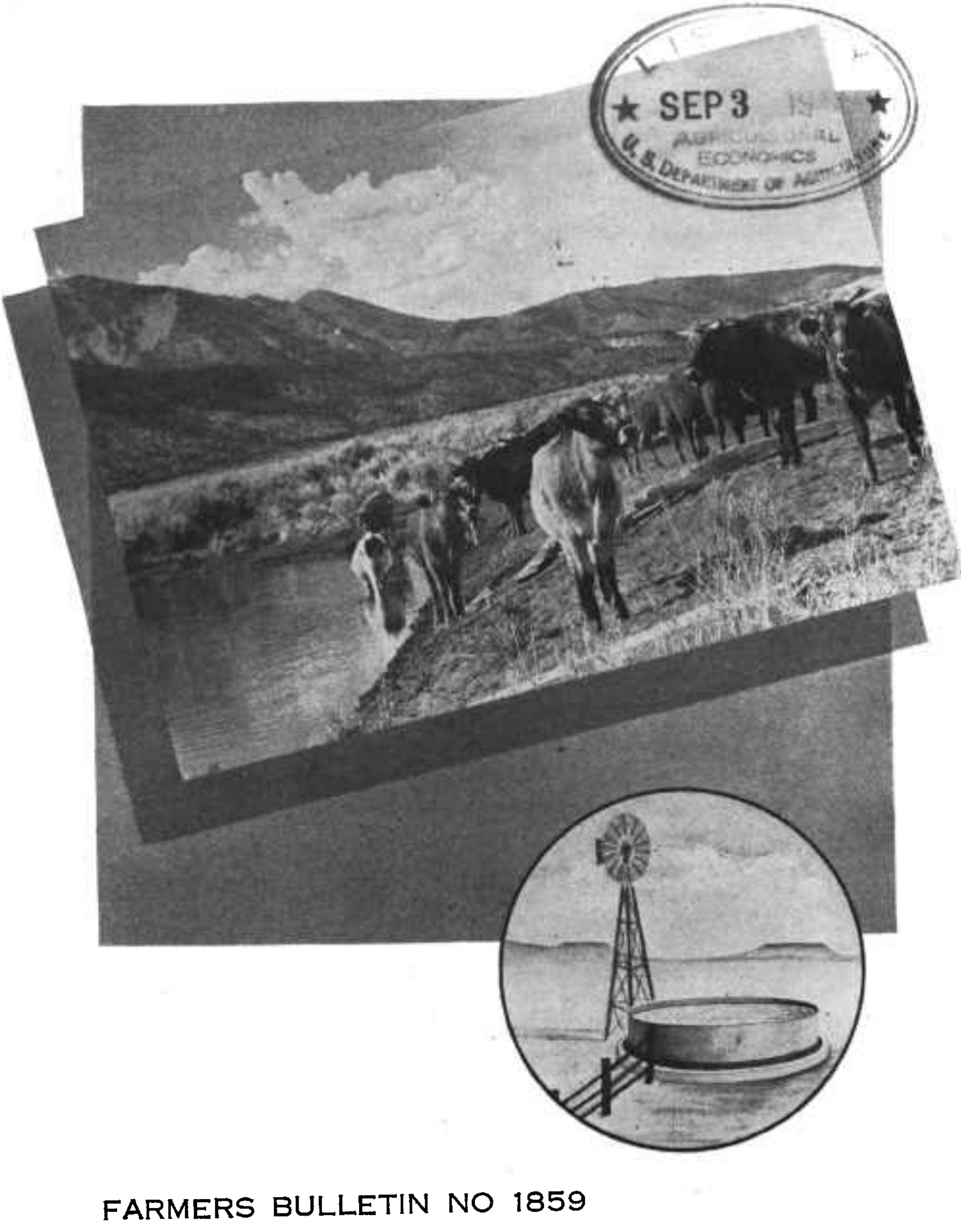
STOCK-WATER DEVELOPMENTS

WELLS, SPRINGS, AND PONDS



FARMERS BULLETIN NO 1859

UNITED STATES DEPARTMENT OF AGRICULTURE

The need for effective utilization of grazing areas and the scarcity of stock water have led to unprecedented activity in the development of water supplies during the last few years as a part of conservation practices in range and pasture areas. Economical construction, planned distribution, and adequacy of stock-watering centers are essential to profitable grazing enterprises. Inadequate coordination of stock-water developments with necessary conservation practices and the improper location or construction of these facilities have made many water supplies unsatisfactory.

This bulletin deals with the requirements and development of stock-water supplies suitable for grazing areas. The information given is based on field experience and observations of experienced stockmen and technicians. The bulletin is not intended to discourage farmers from seeking local advice or assistance, but rather to point out the principal factors that should be considered. Pertinent local information is essential; and consultation with engineers, conservationists, or others experienced in the development of stock-water supplies is advised.

Most States have laws relating to the construction of dams and the impounding of water. These should be investigated and followed wherever they apply. The impounding dams covered in this bulletin are of the earth-fill type suitable for small reservoirs. These are seldom more than 15 feet high and are intended only for relatively small drainage areas.

Washington, D. C. Issued July 1940

STOCK-WATER DEVELOPMENTS:
Wells, Springs, and Ponds

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Contents

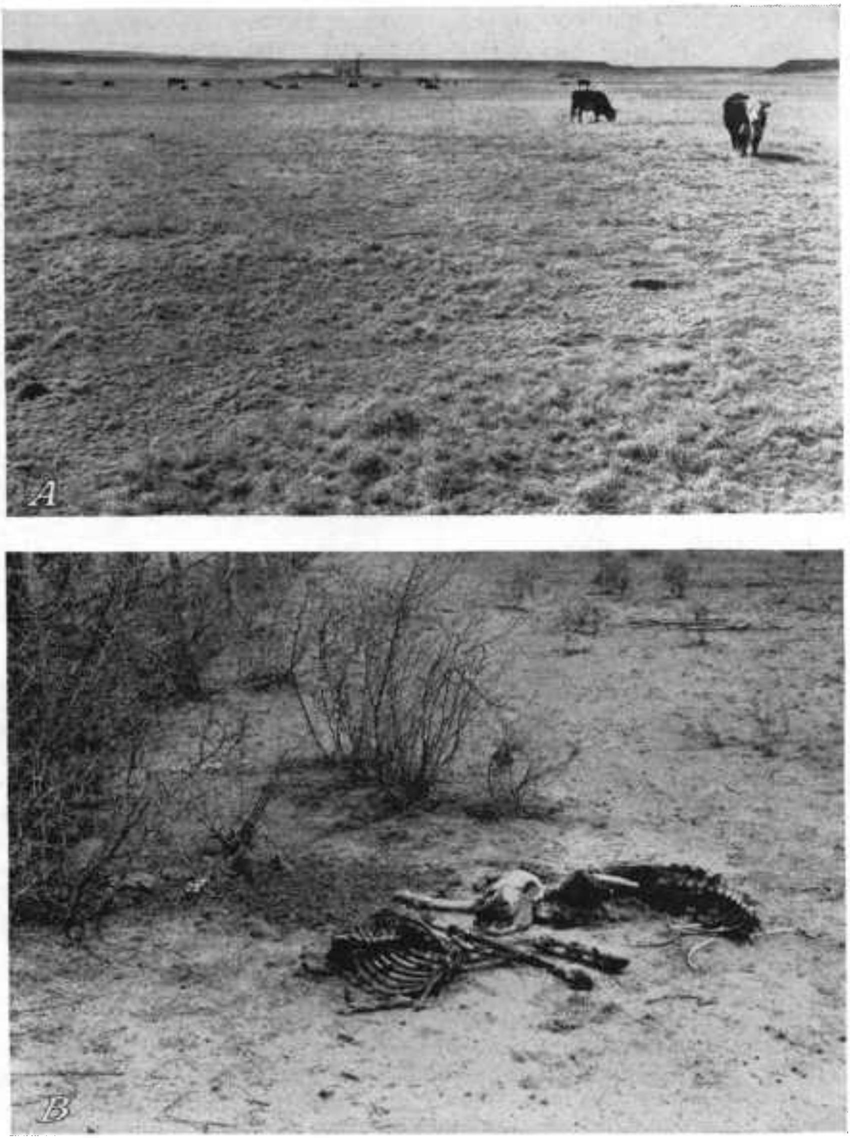
WATER SUPPLIES ON RANGE AND PASTURE

However palatable and plentiful the forage on pasture or range may be, the livestock using it must have all the water they need, or they will not thrive. Water at regular intervals, as well as an ample supply of forage, is essential if livestock are to be turned off in a marketable condition. Inadequate stock-water developments in pasture and range areas not only contribute to an unstable livestock industry and serious livestock losses but prevent profitable utilization of badly needed grazing areas and encourage destructive overgrazing in the vicinity of existing water supplies.

Providing adequate water for livestock on range and pasture is not merely a question of developing enough wells and springs and ponds to supply the water needed by livestock. A proper distribution of stock water in relation to the available forage is equally important (fig. 1). An area capable of supplying an abundance of forage cannot be fully utilized if the water is not accessible to livestock grazing any part of the area. On the other hand, if there is already sufficient water for the number of animals that the surrounding grazing areas will support, additional water developments may merely encourage overgrazing and lead to unnecessary expenditures.

[1] This bulletin has been prepared under the general supervision of T. B. Chambers, Chief, Engineering Division, in cooperation with the Divisions of Agronomy, Range Conservation, and Biology. H.L. Cook, of the Hydrologic Division, contributed the basic material for the section entitled "Rate of Run-off." W. A. Hohlweg, J. B. Thomas, and Frank Hunter, of the Engineering Division, have given valuable assistance, as have also field technicians of the Service.

Livestock require reliable watering places that will furnish water during any season of the year. It is a common experience to have a large surplus of water, particularly in streams and ponds, during wet seasons of a year and a shortage of water during dry seasons of the



NM-335, R4-770

FIGURE 1.—*A*, An excellent stand of buffalo, grama, and galleta grass on a range in the Southwest, where livestock distribution and water facilities have been such as to obtain good range conservation; *B*, an overgrazed range offers little forage for livestock and leaves them in such a weakened condition that they are an easy prey to drought or sickness.

same year. Annual fluctuations in rainfall and run-off add to the problem of providing stable water supplies. The amount of rainfall and run-off on a watershed may vary widely not only from season to season but also from year to year. During wet years reservoirs may be filled several times. During dry years, when the water is most needed and evaporation losses are usually greatest, there may not be sufficient run-off to fill them even once. Serious livestock losses due to inadequate water usually occur during these critical periods.

In pioneer days stockmen in the West located their ranches and pastured their livestock on grazing areas adjacent to running streams or other natural water supplies. The "law of the range" decreed that the first operator in a given territory had a prior claim to the water and range he required. In those days of open range and few fences, feed and water were abundant. Furthermore, the herds or flocks were more or less migratory, following the growth of vegetation and available natural water supplies as the seasons changed. Large tracts of good grazing land were used only during intervals of sufficient rain; and as feed or water began to dry up, the livestock moved to areas with better feed and water. These conditions permitted a flexible system of land use that could be adjusted as necessary to changes in natural conditions (fig. 2).

With the expansion of the livestock industry, ranges became more and more crowded. Legal boundary lines, fences, and other restrictions on the movement of livestock increased. Dependable natural water supplies were soon at a premium, and stockmen often fought for their possession. Continuous and more intensive use of the range necessitated the development of new water supplies. The early efforts to develop additional water supplies were largely confined to digging shallow wells, plowing furrows or ditches to divert water to natural water holes or depressions, cleaning or crudely improving springs or seeps, and constructing small earthen reservoirs. With the continued expansion of the livestock industry and the drying up of temporary water supplies, it was necessary to resort to more permanent storage reservoirs, drilled wells, and other expensive improvements.

It is a common conception that improved livestock-watering facilities are required only in range areas in the arid and semiarid States. The greatest need, of course, is in these areas, but many sections of the more humid States have inadequate watering facilities on farm pastures. Recent periods of drought have revealed these deficiencies. Pasture water supplies that may be well located and have served satisfactorily for several years often go dry during or immediately following repeated dry periods. This is especially true of weak springs, small streams, and shallow wells or farm ponds. Too often livestock from pastures some distance away must be watered from the main farmstead water supply. This leads to excessive overgrazing and trampling of the pasture area nearest to the watering center and great inconvenience in getting the livestock from the pasture to the water supply.

The development of necessary pasture and range watering facilities aids indirectly in the establishment of beneficial soil and water conservation practices in both range and agricultural areas. With proper development and distribution of water supplies, grazing can be restricted on overgrazed, eroded, or depleted range land and the

livestock systematically rotated over other areas according to their grazing capacity. In farming areas adequate water supplies in pastures will encourage more uniform grazing, facilitate pasture-improvement practices, and retard erosion damage. They may also enable

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FIGURE 2.—This luxuriant growth was photographed about 1908 on range that now is a part of the Dust Bowl. Note how sleek the cattle are.

profitable utilization for pasture of soil-conserving crops and erodible or steep areas unfit for producing cultivated crops.

TYPES OF STOCK-WATER SUPPLIES

There are two main types of stock-water supplies (table 1): (1) Natural and (2) constructed. Springs, streams, and lakes are usually considered as natural. Constructed water supplies are those that require considerable drilling, excavation, or construction work to make water available, such as wells, artificial reservoirs, or ditches. The two principal sources from which the water supply is derived are: (1) Surface water and (2) underground water. Streams and reservoirs usually receive at least the greater part of their water supply, if not all of it, from surface run-off. Springs and wells receive their water supplies from underground sources.

Stock-water supplies can be further classified as temporary or permanent, according to their dependability. Intermittent streams or shallow wells and reservoirs usually provide water only during certain seasons or for short periods. Good springs, rivers, or deep wells and and reservoirs are more likely to provide a continuous or permanent water supply. Dew or rain on forage provides a supplemental source of stock water when it can be utilized. Snow may also serve as a source of stock water.

Each livestock-watering unit is usually independent of other watering units on the same pasture or range, and it may or may not be of the same type. One watering place may be a stream; another may be

a well, spring, or reservoir. Sometimes connecting pipe lines supply two or more watering centers from the same source. For example, if an exceptionally good water supply has been developed at one place, it may be more satisfactory to distribute part of this water through pipe lines to other points in need of watering places rather than to develop new ones. This practice is common on farms and pastures in the East, where distances between desirable watering places are not great. On ranges in the West several miles of pipe line may be required between adjacent watering places.

TABLE 1.—*Types of stock-water supplies*

Water source	Natural water supplies	Constructed water supplies
Surface [1]	Reservoirs—ponds and lakes	Reservoirs—excavated and impounding.
	Streams—intermittent and continuous	Ditches—irrigation and drainage.
Underground	Springs—weak and strong	Wells—pumped and flowing.

[1] Primary source except for drainage ditches.

STOCK-WATER REQUIREMENTS

An understanding of stock-water requirements will assure water developments that more nearly serve the purpose for which they are intended, and it will make possible lower costs and fewer unsatisfactory supplies. It is important that watering places on range or pasture be developed to meet the needs of the livestock that will use the grazing areas. The amount of water required, the frequency of watering, and the distances that livestock can travel for water without harmful effects are all important considerations. These vary considerably for the several types of livestock as well as for various range, pasture, and climatic conditions.

Forcing livestock to travel long distances to water is detrimental to both the grazing area and the livestock. On open, relatively flat range land, watering places should ordinarily not be more than 5 miles apart. They should be distributed so that cattle will not have to travel more than 2 to 3 miles to reach water from any part of the range and sheep more than 4 miles. Under some conditions range livestock may graze farther than this from a water supply, but if they do, a satisfactory distribution of the grazing cannot be depended on. Livestock in good condition will travel farther than livestock in poor condition; steers and dry cows will travel farther than other classes of cattle; bands of dry sheep can travel farther than bands of ewes with lambs. These variations, however, usually will not greatly affect the spacing of watering places because of the mixed nature of the livestock on range or pasture.

In rough, mountainous terrain, where timber, rock, or steep slopes make travel difficult, livestock should not be expected to travel more than 1 mile to a watering place. If trails to watering places follow comparatively level ridges or canyons, livestock can travel farther to water without harmful effects. Since animals seeking water usually choose the route of least resistance, merely opening suitable trails or passages to watering centers in rough, timbered, or rocky ranges will help to make travel easier.

On range or pasture the average daily consumption of cattle, horses, or mules is about 10 to 12 gallons per head. Sheep consume daily

about 1 gallon or less per head. The amount actually used and the frequency of watering required vary considerably according to seasons and local conditions. Livestock consume more water and require more frequent watering during the hot summer months and when forage or other feed is dry. During warm weather most range livestock will water every day, but frequently sheep water only every second or third day. During cool weather, and especially when there is considerable moisture on the forage after rain, dew, or snow, range cattle may go for several days without water, and range sheep may go for several weeks. The total amount of water that will be consumed by livestock at one watering place will depend on the average daily consumption per animal, the number of livestock served, and the length of the period over which they are served (fig. 3). If stocking and

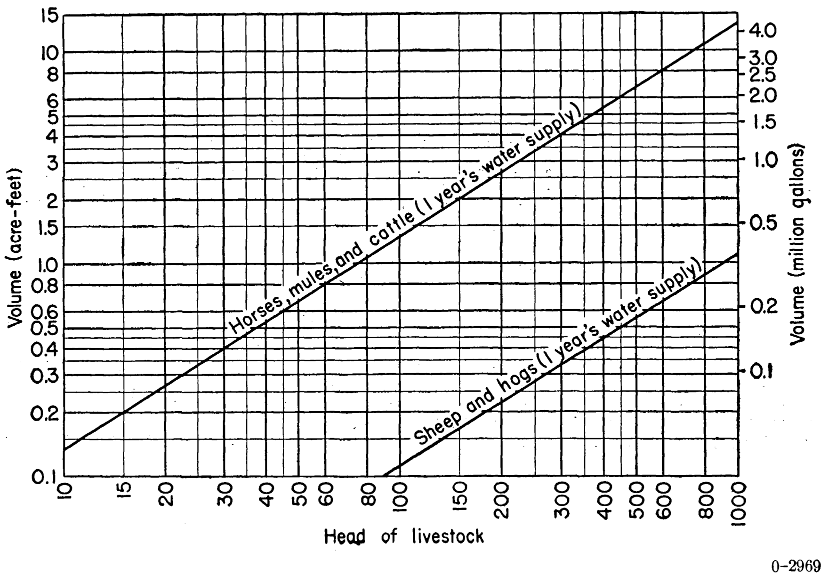

FIGURE 3.—This chart will be of assistance in estimating stock-water requirements. It is based on a 1-year requirement. Ordinarily, stock ponds will receive additional water within that period except during unusually severe droughts, when key watering places must be used. The chart can easily be used for fractions of or multiples of a year as well as for numbers of livestock in excess of those actually shown. For example, 150 head of cattle will require about 2 acre-feet of water for 1 year's supply, 1,500 head will require 10 × 2 acre-feet = 20 acre-feet. (An acre-foot of water is the equivalent of water spread uniformly over 1 acre of surface to a depth of 12 inches.)

forage conditions are similar, four times as many cattle will water at a watering place serving a 2-mile radius as at one serving a 1-mile radius.

Under farming conditions in the East stock-watering places are usually much closer together than on western ranges. Pasture livestock will therefore usually water more frequently, but, if necessary, they can adapt themselves to one watering a day. Dairy cattle and farm horses require more water and more frequent watering than regular pasture livestock.

Under certain conditions it is advisable to heat water, since most livestock will not consume a sufficient quantity during the winter if compelled to drink water that is ice cold. It is also important that the water provided be as clean and as sanitary as possible.

Another factor that is sometimes overlooked is that of the quality of the water. There are some areas, especially in the West, where both surface and underground water are not suitable for livestock because of turbidity, high salt content, or other impurities. In such localities it is advisable to have the water tested before incurring installation costs.

PLANNING STOCK-WATER DEVELOPMENTS

Inadequate initial investigation and planning have resulted in many stock-water developments that have been detrimental to proper land use and grazing practices. Overgrazing near water and unused feed far from water are characteristic results of inadequate planning or development. Many stock-water developments are unsuited to the purpose for which they were intended and represent wasted efforts and expenditures. Although overdeveloped installations may provide ample water supplies, their costs are excessive in comparison with the returns obtained. Underdeveloped installations have caused heavy livestock losses because they failed to provide water during the periods when it was needed most. Comprehensive planning and coordination of watering systems at the outset will usually pay good dividends.

It is important that the total expenditures for water developments be in scale with the potential production or grazing capacities of the areas to which the water is supplied. Since most water developments are costly and since the return from much of our grazing land is low, considerable resourcefulness must be exercised not only in selecting satisfactory types of developments but also in utilizing all favorable local conditions that reduce installation costs. Effective utilization of natural water supplies or those easily made available and skillful selection of sites for artificial developments determine in no small part whether the resulting developments will be profitable or unprofitable investments. The little grazing provided by some areas may not justify sufficient water development to utilize the small amount of available feed.

The expenditure justified for water development on an animal-unit basis is a moot question. There are so many factors to be considered that to indicate specific limits of expenditure is not feasible. Some have stated that ordinarily stock water should be provided at a cost of less than $5 per animal unit served. Others maintain that two or three times this amount can be justified. The problem can be best decided by the person contemplating the water developments.

Most ranches and farms have some natural or constructed stock-water developments. These should usually be utilized to the fullest extent before new reservoirs or wells are constructed. Many old water developments that are not operating satisfactorily but are otherwise suitable can be repaired or reconstructed so as to provide a more economical and dependable water supply than a new one. Risk, as well as construction cost, is usually entailed in new developments.

With new developments, selecting the most suitable type of installation is a problem of determining the type that can be economically developed and maintained. The improvement of existing natural water supplies should be given first consideration. In the absence of suitable streams or lakes, springs should ordinarily be considered next. In areas devoid of all natural supplies, it is usually necessary to resort to wells or reservoirs. Where soils, terrain, and drainage are suitable for the construction of a reservoir, it may provide a cheaper water supply than a well. Though there may be little difference in the maintenance costs of a well and a reservoir, most wells require the installation and operation of pumping equipment. A good well has certain advantages over a reservoir if it can be obtained at reasonable depths. It is less likely to fail when needed most, its location is more flexible, and it usually provides a better quality of water. It is the most satisfactory installation where water is needed for domestic as well as livestock use.

RANGE LAND

The location of watering places is important in controlling the movement, distribution, or concentration of livestock. A comprehensive grazing plan should therefore be decided on before water developments are begun. The plan should provide for a rate of stocking in accordance with the grazing capacity of the range, with total exclusion, if necessary, from denuded and badly damaged areas or on sections otherwise unsuited for grazing. By utilizing natural barriers, fence lines, or other suitable boundaries, the range may be divided into sections and the livestock kept in suitable units so that deferred, seasonal, or rotation grazing can be practiced. This plan will provide necessary forage protection and reserve feed (fig. 4). Further details on the development of range-management plans are given in Farmers' Bulletin 1395, Beef Cattle Production in the Range Area.

After the most desirable range-management practices are determined, the water developments necessary to these practices should be investigated. The extent to which available water supplies can be utilized and the number, type, approximate location, and service periods of new watering places are some of the initial problems. Since most ranches cover relatively large areas, the major problem is to provide numerous inexpensive, easily maintained, and dependable water supplies at centers where water is needed rather than to increase the supply at centers where water is already available or to develop a few large and widely scattered supplies. A watering place to serve each 2,000 to 3,000 acres of range land is a desirable distribution.

If field conditions discourage the development of a proposed watering center, some adjustments in the initial grazing plans may be necessary. For example, let us suppose that to supply water for a certain area a difficult and costly water development is required. Such an installation need not be made if it can be arranged to graze the area during a period when a temporary water supply is available. Economic limitations and field-construction difficulties frequently hinder the attainment of ideal water distribution, and certain concessions must be made in order to assure profitable grazing operations.

In order to get wide distribution of watering places with minimum expenditures, a system of permanent watering places interspersed with

temporary watering centers is frequently used. Primary or permanent water developments are located at strategic points over the range and preferably at intervals of not more than twice the maximum distance that the livestock ordinarily graze from water supplies. Auxiliary or less expensive temporary watering places are developed at intermediate points or in remote corners of the range to provide water for short periods. It is desirable to arrange grazing schedules so that the areas with only temporary supplies are grazed during periods when water is available and to conserve for emergency use the water at the permanent supply. Dew and snowfall can also be advantageously utilized in some areas to enable grazing with minimum expenditures for a water development. Mountainous areas, with their higher precipitation,

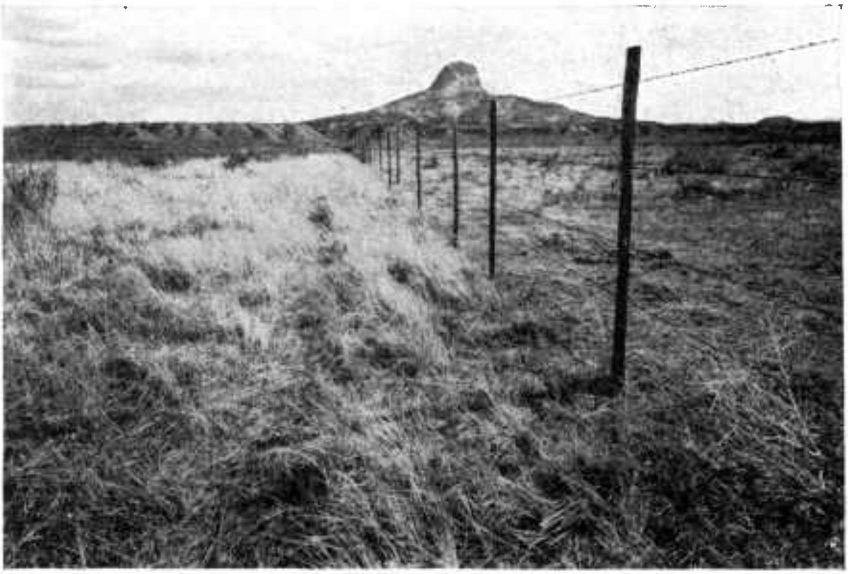

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FIGURE 4.—The field to the right shows evidence of excessive grazing and is readily susceptible to erosion. The protected area, on the left, has an excellent stand of sacaton and galleta grasses.

ordinarily require fewer and less expensive water developments than ranges at lower altitudes or in hotter climates.

Other factors being equal, watering places that can be reached from any direction should be given preference over those that must be approached from only one or two directions, such as sites in narrow arroyos or canyons or at the base of a cliff. Rapid and easy dispersal of livestock after they have drunk relieves congestion and trampling. Dependable water supplies should be given preference over supplies such as weak springs, wells of uncertain flow, or reservoirs with erratic inflows. No stock-water facility should be developed on depleted or worthless grazing areas, on land devoted to timber production or recreation, or on other areas that under a comprehensive land use plan should be closed to grazing.

PASTURE AREAS

In the Central and Eastern States a general type of farming prevails in which the raising and feeding of livestock is usually combined with the production of grain and feed crops on each farm unit. A more intensified type of farming is practiced, and farming units, including grazing areas, are smaller than those ordinarily operated in the West. In the East the greater carrying capacity of grazing areas, smaller farm units, and the intensive type of farming usually make it impractical and unnecessary for a single watering center to serve as large a grazing area as it serves on a western range.

While certain fields are usually retained for permanent pasture, additional grazing is frequently provided by pasturing cropland after

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FIGURE 5.—A fenced pasture lane facilitates the watering of livestock by giving access to distant water supplies.

the crop is harvested or during a rotation period when forage crops are grown. The grass or other forage crops that are being used more and more extensively in crop rotations can often be utilized to best advantage by pasturing. Farm reorganization for the establishing of proper land use and conservation farming practices usually introduces the problem of watering livestock on fields that provide either permanent or temporary grazing. Inadequate water facilities on these fields may jeopardize the use of the soil-conserving practices planned for these fields.

In the development of new watering facilities pastures or fields designated for permanent grazing should be given preference. It is frequently not practical to provide stock water in all fields that will be used for only temporary or supplemental grazing. For these fields an arrangement of gates to facililitate the driving of livestock back and forth to water supplies may be all that can be economically justified.

Since local conditions and requirements vary, the owner of each farm or the one who plans for the grazing of livestock must exercise considerable resourcefulness in providing water at the most suitable centers. An arrangement of field boundaries to include water or fenced lanes (fig. 5) to enable livestock to travel to water or the use of pipe lines to convey water to grazing areas will often make possible a more effective use of developed water supplies. Dependability, economy, conveneience, and coordination with proper land use are tests of successful installations.

SUPPLEMENTAL USES

Certain types of stock-water supplies, particularly surface reservoirs, have many supplemental uses. A stock-water reservoir that serves two or more purposes can often be constructed in a location that would ordinarily not justify the expenditure if the reservoir served only one purpose, and it may become one of the most valuable investments on the farm.

While the total amount of run-off retained by a single farm reservoir may be small, the large number of reservoirs that will be constructed in some sections will provide a total run-off-retention capacity of considerable magnitude. The run-off retained may increase the soil-moisture content and ground-water supplies, particularly in the immediate vicinity of permanent reservoirs.

Under certain conditions it is possible to use the reservoir as a catchment for the run-off from terraces and diversion ditches. Such an arrangement may reduce considerably the cost of providing disposal facilities. Stock ponds that are large enough may be used as recreation centers, where swimming, picnicking, or boating can be enjoyed. In the North, ponds may also provide skating and a source of ice for farm ice houses.

The most important supplemental uses to which stock-water reservoirs may be put are gully or arroyo control, supplemental irrigation, and wildlife development.

When a reservoir is used for the dual purpose of stock water and gully control (fig. 6), the impounding dam is usually located in the gully, where it checks further erosion by retention of water in the gully or diversion of run-off from the gully. The reservoir may also be constructed to the side of the gully and the run-off diverted from the gully into the reservoir by means of a diversion ditch. Wherever stock ponds can be constructed in gullied areas, such opportunities should not be overlooked in the initial planning and selection of sites. It must be remembered, however, that in most reservoirs used in gully control there is likelihood of silting.

In arid and semiarid areas it is often possible to use a stock-water reservoir as a source of irrigation water. Merely locating reservoirs so that the overflow can be advantageously spread over flattish grazing areas simplifies spillway construction work and may increase the forage on the flooded area as much as twofold or threefold. Locating reservoirs of adequate capacity directly above areas suitable for growing gardens or small acreages of feed crops may make it possible to subirrigate the crops or vegetables grown on these areas. If necessary conduits are provided, water that is surplus to the livestock needs can also be effectively utilized for direct irrigation. Gardens and small areas of valuable feed crops are often saved during drought

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periods by pumping or hauling water from some nearby reservoir.

In areas where natural ponds and lakes are scarce, stock-water ponds can become valuable assets in the conservation of wildlife (fig. 7). With little effort a farm pond can be converted into a wild-

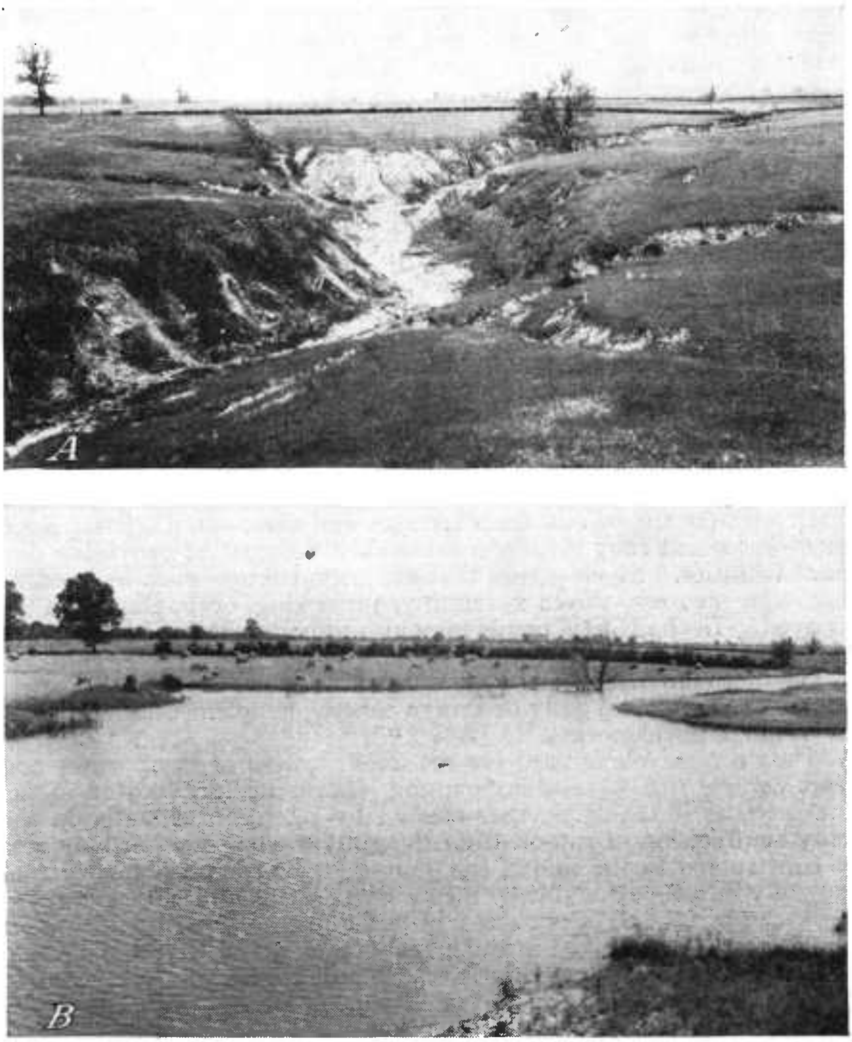

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FIGURE 6.—*A*, View of a gully before an impounding dam was constructed. *B*, The same place about 2 years later. Erosion within the gully has been checked.

life habitat that will not only benefit wildlife but provide recreation for the owner. It may even be made a source of income through the raising of fur-bearing animals or charges for hunting privileges. In sections of the East it has been found that ponds properly constructed and managed will produce better fishing than is found in many lakes

and streams. As much as 150 to 300 pounds of fish can be removed annually from ponds with 1 to 2 acres of surface area and a depth of about 10 feet. Intensive use of the pond by wildlife does not materially detract from its usefulness for watering livestock.

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FIGURE 7.—This pond in the Southwest is an excellent wildlife site. The mallard ducks in the foreground were hatched and raised at the pond.

Ponds effectively planned and utilized for dual purposes of this type become an investment that adds to the sale value of a farm and provides healthful recreation for the family.

WELLS

Good wells furnish one of the most satisfactory sources of stock water. But precaution must be taken in selecting the well site. Many attempts to obtain wells have resulted only in dry holes, an unsatisfactory or inadequate water supply, and the consequent wasted expenditures. Such waste can be avoided to a large extent by carefully investigating the probability of getting a satisfactory well in any proposed area before construction. One of the best means of doing this is to study the location and performance of existing wells in the vicinity of the proposed well. In some areas enough dry holes or unsatisfactory wells have already been obtained to discourage any further attempts to get a good well. In untried or doubtful areas, the advice of experienced local well-drillers and geological authorities should be sought. The Geological Survey and State geologists can usually furnish definite information on the availability of ground water in most States. Geological formation, land slopes, vegetation, and similar indications enable experienced persons to determine the probability of finding suitable ground-water supplies. Even though the information obtained indicates that ground water is available in

the general vicinity of a proposed location, an element of risk is always involved. The exact depth to water and the amount available at any location cannot be determined until a hole has actually been sunk and the well tested.

It is desirable to penetrate a good water-bearing stratum at the least depth possible. Methods of sinking deep wells differ in most respects from those of sinking shallow wells. Wells can usually be put down in shallow water-bearing strata cheaper than at greater depths and with simpler equipment than is required for drilling deep wells. Farmers or ranchers often dig, bore, or drive shallow wells themselves. Well drilling is a specialized type of work and is usually done by contractors equipped for the business. Considerable experience is necessary to acquire drilling technique, and a variety of tools and appliances are required for penetrating and removing various kinds of formations or for overcoming other difficulties encountered in drilling.

Wells ordinarily are dug, driven, or drilled. In some areas bored wells are used. Various local adaptations and construction methods are used with each type of well. The most suitable method to use in sinking a well will depend on the type of material to be penetrated, the depth and nature of water-bearing strata, the well requirements, and the construction facilities available.

Dug wells are usually considered only where adequate water can be obtained within 30 to 40 feet from the surface and where the excavating can be done with hand tools. The large storage space provided by dug wells is advantageous in a water-bearing stratum that is slow to deliver water. A bored well is sunk with an excavating auger, and in essentials it is similar to a dug well.

Driven wells are used where a good water-bearing stratum can be penetrated at a shallow depth. A well cannot be driven where there is rock or other formation difficult to penetrate. Where applicable, driven wells are generally cheaper to install than dug wells of the same depth.

Where the ground formation is difficult to penetrate or the water-bearing stratum a considerable distance from the surface a drilled well is usually the most economical and satisfactory. The deeper water-bearing strata that supply drilled wells are usually the most satisfactory source of stock water because the water is less likely to fluctuate with changes in climatic conditions and is more easily protected from surface contamination.

CONSTRUCTION

Dug wells (fig. 8) are generally circular excavations 3 feet or more in diameter. Where weak inflows are encountered and underground storage capacity is a significant factor in securing an adequate water supply, larger diameters may be desirable, even though they require additional excavation. A well 4 feet in diameter will provide twice as large an infiltration area and four times as much storage space as one 2 feet in diameter. Occasionally, dug wells with depths of as much as 50 feet or more have been excavated where ground formations are favorable. To obtain water at shallow depths it is often preferable to select a site near a wash or other low area but out of the flood plain so that the well will be safe from floodwaters and undesirable surface drainage. Owing to the shallow depths of dug wells the

water supply may fluctuate considerably with changes in climatic conditions. They often go dry during dry spells but usually respond quickly after heavy rainfall. Their construction, however, is not difficult, and expensive materials or excavating equipment are ordinarily not required.

One of the principal requirements in the construction of a dug well is a properly constructed curbing to prevent caving and harmful surface infiltration. Wooden linings have been used, but they are usually short-lived and are difficult to seal. The most satisfactory well linings are constructed from the more durable materials such as stone, brick, concrete, tile, or metal. If the curbing is not built directly against the face of the excavation, it is usually desirable to backfill with a porous material any space that may be left between the earth wall and the outer edge of the curbing except the upper 8 to 12 feet, where an impervious seal should be provided to prevent the infiltration of surface pollution. Reinforced concrete is the most suitable material for constructing the curb cover and pump base. The cover may be constructed as shown in figure 8, or the pump may be set to one side of the well and a separate manhole placed toward the other side of the cover. The top of the well should be constructed high enough and the ground around the well should be so graded that waste water or run-off will readily drain away from the well.

An ordinary driven well is obtained by placing a special point and screen assembly on the end of a pipe from 1 to 1½ inches in diameter and driving it into the ground with a wooden maul or block until the water-bearing stratum is penetrated. The upper end of the pipe is then connected with a suitable pump. There are various ways in which a driven well may be sunk, depending on the available tools and the nature of the material to be penetrated. Even though driven wells are comparatively cheap and simple to install, difficulties of pumping and driving usually limit the depths and sizes of these wells. They may require frequent inspection and repair as a result of clogged screens. The rate at which water is delivered from wells of this type is usually low, and it may fluctuate considerably unless the source is unusually favorable. It is often advisable to drive a temporary test point and check the possible yield, quality, and depth of water before installing the final well unit.

An improved type of driven well is shown in figure 9. A short piece of ordinary well casing is inserted in the ground and the regular closed-end well point driven inside. A screen suitable for the fineness of the sand encountered should be selected. The operating depth of this installation cannot be more than about 25 feet below the pump cylinder owing to the practical limits of suction lift. Where the ground is hard and driven wells of larger sizes and greater depths are desired, the open-end driven well is often used. Ordinary well casing is forced into the ground until the water supply is penetrated. A steel cutting edge or casing shoe is placed on the lower end of the casing. Continual removal of the earth from the inside casing with a water jet or mechanical pressure will expedite the work of sinking the tube. The lower portion of the casing may be perforated with small holes, or a solid tube may be sunk and then fitted with a suitable strainer. A regular pump with necessary supply pipe is installed inside the driven tube. If a satisfactory water supply is obtained, the top of driven

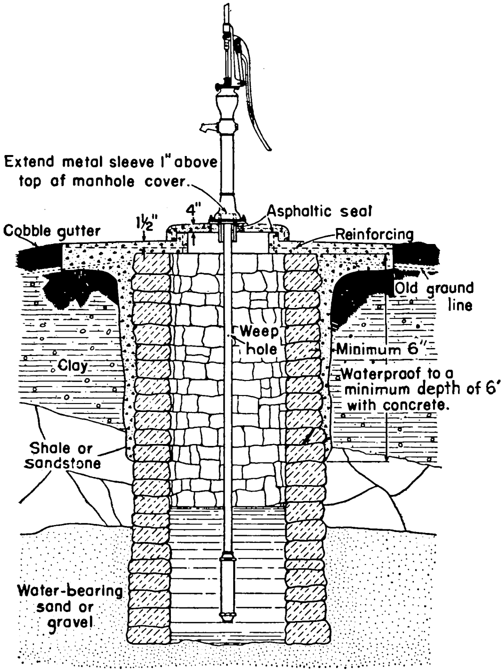

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FIGURE 8.—A dug well with masonry curbing. The upper curbing should be sealed to prevent infiltration of surface water.

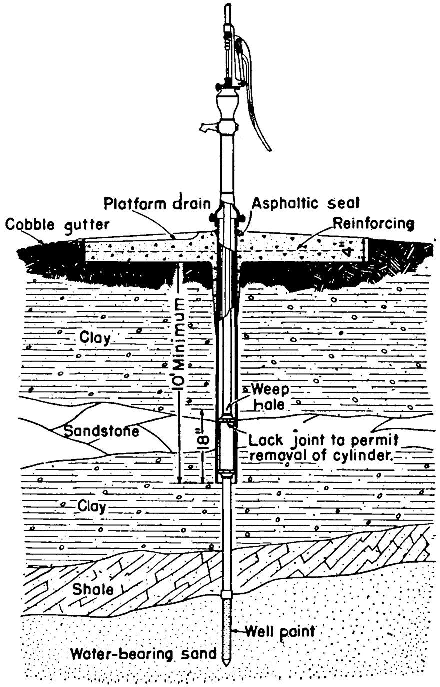

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FIGURE 9.—An improved type of driven well. The well point should penetrate into the water-bearing stratum far enough to assure full usage of the screen.

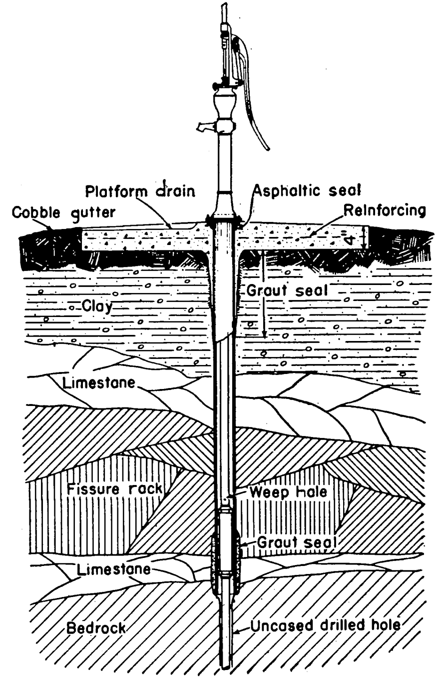

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FIGURE 10.—A drilled well, showing method of sealing both at the top of the drill hole and through a porous stratum such as limestone.

wells should be sealed and provided with a concrete platform similar to that used on other types of wells.

Ordinarily drilled wells for stock water (fig. 10) are provided with 4- or 6-inch casings and are less than 300 feet deep. If irrigation requirements must be met, larger diameters than these are common. If necessary, deeper wells can be drilled, but the drilling of these wells and subsequent operation and maintenance of the well are expensive. The drilling is usually done by experienced drillers, who use special drilling equipment. Regular drillers have had the experience to cope with the problems that arise during the construction of drilled wells. Care should be exercised to employ only competent drillers, since there are many deceptions unscrupulous drillers can resort to in fulfilling contracts. Furthermore, many a potentially good well has been ruined or abandoned because the individual in charge did not understand the various expedients that could have been used to make a producing well out of one that appeared to be a failure. It is usually desirable to have well-drilling contracts or agreements drawn in a flexible form, since unforeseen conditions are likely to arise during the construction work. Even though considerable information is available as to the depth at which a suitable water supply will be found, the uncertainties in well drilling make it difficult to write a drilling agreement acceptable to both parties that will assure a satisfactory well at the least cost. Usually the greater the minimum amount of drilling a driller is assured, the cheaper the drilling costs per unit foot. It is usually advantageous to both parties, if a competent driller is employed, to make payment on a unit basis for the actual depth drilled and the amount of casing or other material installed. A definite understanding at the outset as to the basis on which a proposed well is to be paid for is desirable. In any event, a new well should not be considered as complete or satisfactory until a pumping test of suitable continuous duration has been made.

Well supplies are subject to pollution both at the surface and through underground fissures. As wells are the principal source of domestic water supplies in rural areas, it is important that they be properly protected from contamination. Even though a well may appear safe, the water should be checked for bacterial infection at frequent intervals if it is for domestic use. State health departments are usually equipped to make the necessary analysis. Shallow wells are more susceptible to pollution than deep wells. It is important that wells be located a safe distance from any known source of pollution such as floodwaters, privies, cesspools, sinkholes, barns, or industrial wastes. It is also important that wells be sealed against surface pollution, particularly at the surface and 8 to 12 feet below the surface. The top of a well should be about 1 foot above the surface of the surrounding terrain and sealed with concrete as shown in figures 8, 9, and 10, if the water is to be used for human consumption as well as for stock water. Additional information on methods of protecting, disinfecting, and maintaining safe water supplies can be obtained from State colleges or health departments.

After a well has been completed and has satisfactorily passed a pumping test, it should be properly equipped for operation. Except for flowing wells, which are occasionally found in some areas, the water must be pumped. The pumping equipment for small wells has been standardized to a large extent, and reliable pump manufacturers

supply information on the selection, capacity, and power requirements of their equipment. Pumps that fit the well and have the necessary capacity should be selected. Where large quantities of water are required, pumps are seldom operated by hand power; windmills, internal-combustion engines, and electrically-driven motors are the most common source of power. In the Middle West and West, windmills are probably used most extensively because winds are favorable and the cost of windmill operation is low. Windmills may be provided with an auxiliary engine or motor for emergency use during break-downs or long calm spells (fig. 11). It is important that windmills have towers high enough to obviate wind interference from nearby obstructions and that they be strong enough and properly anchored to withstand high winds. Ordinarily, engines and motors pump water faster and furnish a more dependable source of power than do

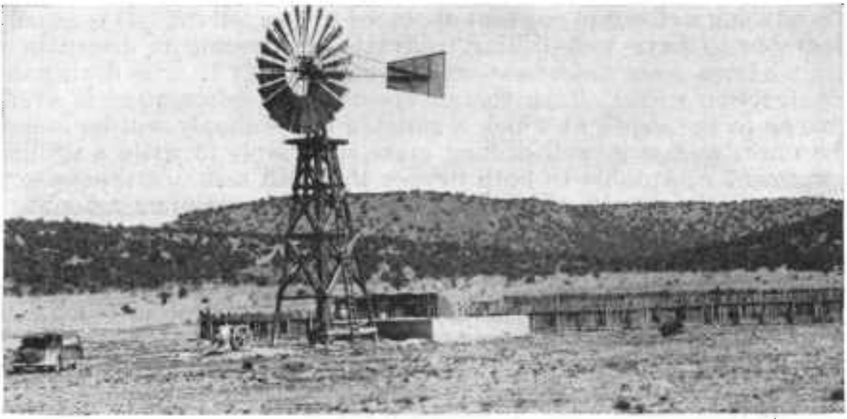

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FIGURE 11.—A well that has been equipped with both a windmill and an auxiliary gasoline engine.

windmills, but they are more expensive to operate. The use of electric motors is, of course, dependent upon the availability of electricity. It is preferable to protect engine and motor equipment from the weather, and in the Northern States it is essential that all well installations be protected from freezing.

More detailed information on wells can be found in United States Department of Agriculture Circular 546, Putting Down and Developing Wells for Irrigation.

TROUGHS AND TANKS

The use of watering troughs and storage tanks is essential with certain types of stock-water developments. Watering troughs are necessary at wells and springs; and, with the possible exception of some installations on the range, it may be desirable to use them with impounding reservoirs also. If the watering trough does not provide sufficient storage, an auxiliary storage tank is necessary. Where large herds of livestock are to be watered, the flow from low-yielding springs and wells is often collected in auxiliary storage tanks, from which watering troughs are supplied. Adequate storage facilities are

particularly needed for wells operated by windmill power because calm periods may prevent windmill operation for several days at a time (fig. 12). One or more low tanks with large capacities are often used as a combined storage tank and drinking trough. Additional storage facilities are not necessary with reservoirs because the water can be drawn direct from the reservoir as it is needed.

The need for storage tanks and the capacity required will depend largely on the flow available from the water supply, the number of livestock, and the dependability of the pumping unit. Where windmill power is depended on for pumping, it is desirable to provide sufficient storage for about 1 week's water supply. Sufficient storage should be provided for springs to maintain adequate water in drinking troughs at all times. If storage requirements are relatively small,

Ariz-3524

FIGURE 12.—A large concrete storage tank fed by a windmill. The drinking trough is in the immediate foreground. Note the float-valve control in the center of the trough.

combination storage and drinking tanks are usually the most satisfactory and cheapest. If greater storage requirements are necessary, wooden, steel, or concrete storage tanks are commonly used (fig. 12). For the large storage capacity required on many ranges, an excavated earth reservoir is the cheapest (fig. 13). A circular excavation 3 to 4 feet deep in an impervious soil is often used, and the excavated soil is piled around the rim to increase the capacity of the reservoir. Livestock should be excluded from storage reservoirs of this type and watered in troughs fed from the reservoir. In the West a combination storage and drinking trough of galvanized iron or steel sides and puddled clay or concrete bottom has been used to provide considerable storage without undue expenditure.

In order to avoid crowding, sufficient drinking space should be provided at troughs to water without undue delay the full number of livestock that come to drink at any one time. About 2 to 3 feet of drinking space should be provided for each cow or horse. Troughs

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FIGURE 13.—A natural storage tank on a western range. Such tanks are successful only in impervious soils.

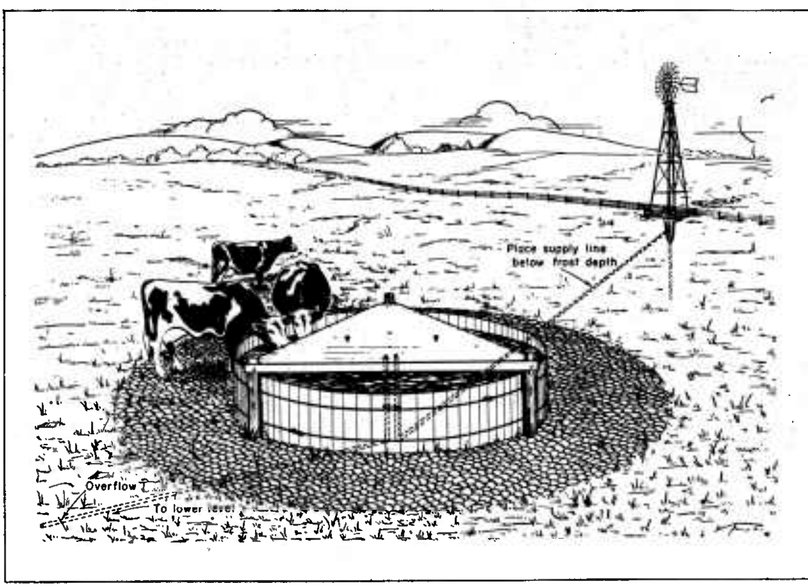

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FIGURE 14.—A typical trough and windmill installation. The trough has been equipped with a guard to prevent livestock from being crowded into the trough. The guard has a hinged cover to allow easier cleaning of the trough. For wide troughs such as this a guard is desirable.

with a top width of 2 feet or more can be used from both sides if properly located. Wide troughs should be provided with suitable guardrails to prevent livestock from stepping or being crowded into the trough (fig. 14). Ordinarily, cattle and horses feed and travel to water in small groups of about 10 to 12. On open level or rolling terrain larger groups may come to water at one time than in rough, brushy ranges or pastures. Sheep, whether herded in bands of a thousand or more or run as farm flocks, usually water in large numbers, and they should therefore be provided with a sufficient number of long troughs that are narrow and shallow. To reduce excessive crowding and the number of troughs required, it is sometimes necessary to split large bands of sheep into smaller flocks for watering. Cattle troughs range from 1½ to 2 feet in height, the lower heights being preferable for calves and other young livestock. Ordinarily, sheep troughs should not be more than 1 foot high. All stock troughs should be anchored sufficiently to prevent livestock from moving them or tipping them over.

If properly constructed, reinforced concrete troughs are usually the most satisfactory for permanent use because of their durability. Information on concrete mixing and the construction of concrete troughs is given in Farmers' Bulletin 1772, Use of Concrete on the Farm.

Wooden troughs constructed from 2-inch material, well braced, and, preferably, painted are satisfactory if they are not exposed to frequent drying out. Reinforced galvanized metal troughs are durable, lightweight, and of moderate cost. Substantial masonry foundations are preferable for most troughs, for they provide support, anchorage, and alinement. Circular and rectangular troughs are commonly used for cattle or horses and V- or U-shaped troughs for sheep (fig. 15). Circular troughs provide the greatest storage capacity per unit of construction materials used, and rectangular troughs give the greatest drinking space in proportion to their capacity. Circular concrete troughs are usually more difficult to construct than rectangular ones owing to the forming that is required. Commercially constructed steel or wooden troughs of various capacities, either circular or rectangular, are available.

Troughs should be placed in a well-drained and easily accessible location. They should be high enough to be safe from floodwater, yet low enough to be supplied by gravity flow. Since there is usually some slopping of water or seepage and heavy trampling by livestock around troughs, frequent maintenance work may be necessary to keep the area around a trough in good condition. To prevent the formation of mudholes, a layer of broken rocks, sand, and gravel should be worked or pounded into the soil around the trough (fig. 14). A concrete platform around the trough may also be used; it makes a durable and lasting arrangement. Depressions can be repaired by filling them with a layer of rock covered with a mixture of clay and gravel. All troughs should be fitted with adequate overflow pipes to carry waste water away. Troughs supplied by gravity from reservoirs or storage tanks can also be provided with a float control that automatically maintains a constant water level in the trough. With this control there will be no waste of water nor the annoyance of manually operating control valves, and a more constant water supply is assured. Where windmill or electric pumping power is used, a float arrangement on the storage tank or trough may be used

to advantage for automatically starting and stopping the pumping unit. Suitable devices can either be made from salvaged materials or purchased from windmill or pump-manufacturing companies.

Stock troughs should be provided with a drain opening that is at least 1½ inches in diameter and flush with the bottom. This opening is necessary for draining and cleaning the trough. The dirt and other debris that gradually accumulates in open troughs should be removed at intervals to keep the trough as sanitary as possible. In some areas the development of algae, moss, and other forms of plant life in watering troughs often becomes troublesome. This growth may cause disagreeable tastes or odors and encourage bacterial development,

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FIGURE 15.—A group of U-shaped troughs arranged in series and protected with guardrails. Water is received from a spring within the small fenced enclosure. The troughs are intended for sheep.

besides giving the trough an unsightly appearance. Frequent cleaning is the most desirable preventive, but small quantities of bluestone (copper sulfate) may sometimes be used advantageously in addition to cleaning to check the development of algae. But since bluestone is poisonous, merely washing the trough with a dilute solution of copper sulfate will probably be a safer procedure.

It frequently occurs that birds and small rodents fall into a watering trough while attempting to obtain a drink. Usually they are unable to get out, and within a short time they drown. Unless removed, they contaminate the water. By placing several pieces of wood in the trough to float about or, better still, by hinging one end of a board to the top of the trough and allowing the lower end to float on the water surface, a means of escape is provided. The board should be long enough so that when the water in the trough is low the board will rest on the trough floor at an angle flat enough to enable the animal to gain a foothold.

All pipe lines between water supply and troughs or storage tanks must be protected from livestock. Guardrails may be used; or the pipe lines may often be placed underground to advantage, especially in the North, where protection from freezing must be provided for most stock-water developments (fig. 16, *A*). It is advisable to place pipe lines below the frost line. Those above the frost line usually require some type of insulation, and they should be fitted with necessary stop and waste valves to facilitate drainage when not in use. In the North watering troughs and storage tanks also require protection from freezing during cold periods. During very cold periods it may be necessary to use special tank heaters not only to keep the water from freezing but to keep it from becoming too cold for satisfactory consumption by livestock. At other times the water can be protected by covering the troughs, except for a small area at one end, where the livestock drink, with a good layer of hay, straw, or manure (fig. 16, *B*). A hinged cover for the open end, which can be closed when livestock are not drinking, will give more complete protection.

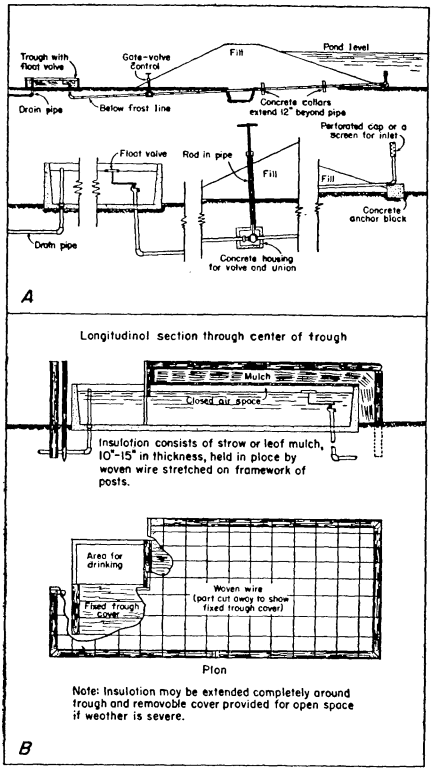

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FIGURE 16.—*A*, A method of protecting pipes from frost; *B*, a simple but effective way to insulate a watering trough against freezing.

SPRINGS

Springs are the natural emergence of ground waters that find their way to the surface through crevices or porous earth strata. They are of all gradations between concentrated outflows emerging from the ground at a single point or within a restricted area, which are characteristic of true springs, and the diffused emergence of water over large areas, which is characteristic of general seepage. Ordinary springs have a fairly steady flow that may vary from a few gallons per hour to several gallons per minute. The approximate yield of a spring can be obtained by determining the time required to fill a container of known capacity. Even springs with low flows can usually be developed so as to provide a dependable water supply for a considerable number of livestock.

To develop a spring, it is necessary to clean out the opening, locate the true water-bearing outcrop, and provide means for collecting

and utilizing the outflow. The spring should be protected from surface damage, and suitable cribbing and collecting facilities should be provided to keep the collecting sump and inflow channels open.

There are three general kinds of springs: (1) The encased spring, which is provided with a removable cover; (2) the closed spring, which is completely sealed or sodded over; and (3) the open spring, from which livestock water directly. The most satisfactory kind of spring development will vary somewhat according to the type of spring.

Springs may be divided (1) according to their mode of origin, into gravity and artesian springs; (2) according to the nature of the passages traversed by the water, into seepage, tubular, and fissure or fracture springs; (3) according to the manner in which the water is brought to the surface, into depression springs and contact or hillside springs (fig. 17). Another term sometimes used for depression springs is low-area or water-table springs.

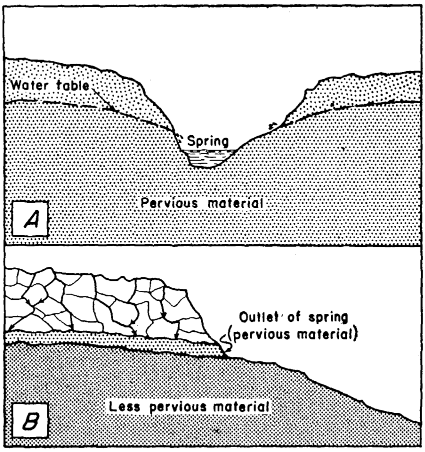

FIGURE 17.—*A*, A depression spring, sometimes called a low-area or water-table spring; *B*, a contact spring, also known as a hillside or perched water-table spring.

A gravity spring is one whose water flows through pervious materials or passages under the action of gravity in a manner similar to that in which a surface stream flows down its channel. An artesian spring is one whose waters are confined in impervious channels or between impervious beds and are under pressure because the water level at the source is higher than at the point of emergence.

In a seepage spring the water percolates or filters through pervious material; in a tubular spring it emerges from tubular passageways that have developed in drift, limestone, or other soluble rock; and in a fissure or fracture spring it emerges along joint, cleavage, and fault planes or other openings of a sheetlike shape.

The term "seepage spring" is usually associated with springs of small discharge. Any considerable area in which water is seeping to the surface is commonly called a seepage area. It is also common practice to refer to a seepage spring or area as a seep.

Depression springs emerge at points where the earth's surface dips or extends down into the water-conveying stratum or water table. They often appear as seepage areas in draws or depressions on relatively flat plains. The contact or hillside spring usually emanates from slopes and is formed by water flowing to the surface through a permeable layer over on outcrop of less permeable material.

It is desirable to determine the characteristics of a spring before undertaking to develop it so that the work can be adjusted to utilize and protect the spring most effectively. Many springs have been rendered useless because no attempt was made to determine the type of these springs before construction was begun, and they were improperly developed. Most of the springs that will require develop-

ment to procure stock water will be of the gravity type and will be either depression or contact springs.

The resistance to outflow, or the head under which the water discharges, has a direct effect on the yields and the ultimate success of a spring development. Reducing the resistance to outflow by excavation or cleaning and thus lowering the head against which the spring must discharge tends to increase the yield. Increasing the resistance to outflow or raising the point of discharge tends to decrease the yield. While the yield of an improved spring may sometimes be controlled by changing the height of discharge, this practice must be used with caution. Raising the point of discharge by only a few feet often causes complete loss of flow by forcing the spring to change its course and emerge at some other point. Ordinarily, the head under which a spring must discharge should be reduced to a minimum and should seldom be increased more than 1 foot for the average small spring.

The development of seeps is often a gamble and may also be more expensive than the improvement of ordinary springs because of the extra work that may be necessary to utilize every drop of water that the seepage area is capable of yielding. It may be possible, however, by extensive excavation, ditching, and tiling to obtain a worth-while supply of water from an area that appeared to be only a wet or swampy spot. A mere drip of water from some seam in a ledge can often be developed into a satisfactory water supply by drilling a hole several feet deep into the rock close to the seep and springing it with a small charge of explosive. Successful results are largely dependent on the initial selection of seeps that indicate a substantial yield and on the care and resourcefulness exercised in the development work.

DEPRESSION SPRINGS

It is often difficult to determine the most suitable form of spring development until some excavating has been done and an investigation made. Before undertaking an extensive development, it may be advisable to make numerous test borings in the immediate vicinity of the spring to determine the approximate water-table profile and the extent and direction of movement of the water. A study of the relative heights to which water rises in a group of test holes will make possible a better-planned collection system.

A spring encasement box is usually used in the development of depression springs where the inflow is primarily upward. After the spring is excavated, a cribbing 3 or 4 feet square with a tight-fitting cover and outflow pipe is installed. The walls should extend a few feet above the ground and deep enough to reach a good foundation. The cribbing may consist of masonry, concrete, or other similar material. A circular encasement is made by using an old barrel for a form and pouring concrete around it or by cribbing the excavation with such materials as brick and rock. The lower part of the encasement wall should be porous if there appears to be some horizontal inflow of water. The encased spring with removable cover is desirable if household water is to be obtained from the spring because with such an arrangement it is easy to make frequent inspections and cleanings.

Some springs emerge in such flat terrain or at such low points that it is impossible to pipe the water to a trough within a reasonable distance because of insufficient head for gravity flow. Where this occurs it may be possible to utilize an open-type collecting basin from which

livestock can water directly, if necessary protection can be provided against run-off and other surface hazards (fig. 18). If a seepage area is encountered, it may be desirable to drain the water into a central encasement. The drains may consist of gravel-filled trenches or of pipes and should extend sufficiently far into the seepage area to collect as much water as is needed. The trough must be located away from the seepage area in order that livestock may not bog down. Many springs that do not yield sufficient water to supply troughs

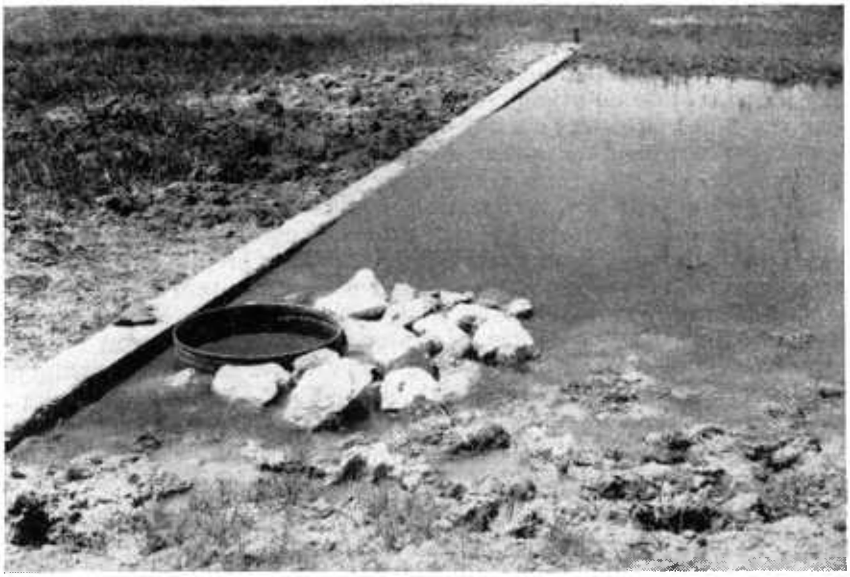

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FIGURE 18.—An open-type collecting basin for a depression spring. Livestock utilize the basin for a drinking trough. If there is considerable overflow water, it should be wasted through an overflow pipe that discharges at some distance from the trough.

direct may require only a storage reservoir to provide a useful watering place.

CONTACT SPRINGS

Contact springs generally emerge on hillsides, and the inflow is in a downward or horizontal direction. The water percolates from passages or numerous small openings in the permeable material, which overlays a less pervious stratum. The discharge may be restricted to one point or to a limited area, or it may extend a considerable distance across the slope. Improvement and maintenance of flow depends largely on horizontal excavation and increased discharge along the top of the impervious stratum. A suitable development must intercept the inflow and collect it at some central point. Vertical excavation or borings through the impervious stratum may result in complete or partial loss of spring flow.

A V-shaped collecting wall with the ends extending back into the hillside to divert the water to a central point at the apex is commonly used in developing contact springs (fig. 19). A concrete collecting wall is preferable, and it should be at least 6 inches thick, with the

ends extending far enough back into the hillside to prevent out-cropping water from going around them. The wall usually extends 1 to 2 feet above ground level, and it should be carried deep enough

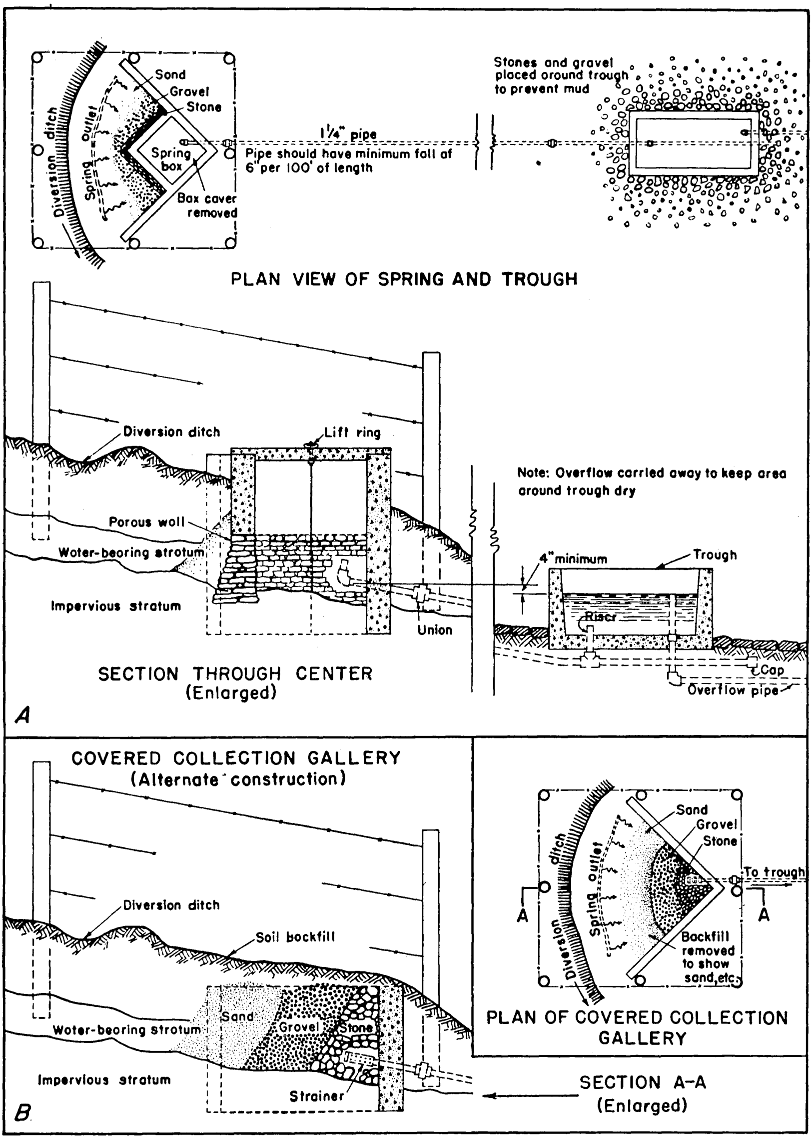

FIGURE 19.—*A*, Plan view and cross section of an installation for a contact spring. The spring box is provided with a removable cover. *B*, Installation similar to that in *A*. The spring box has been eliminated and a filter of sand, gravel, and stone used in the collection gallery. This is a cheaper type of installation.

to reach a good foundation and prevent underseepage. A galvanized pipe of adequate size, seldom less than 1¼ inches in diameter, is inserted at the desired height near the apex of the collecting wall to

convey the spring discharge to a watering trough or reservoir. If frequent inspection and cleaning is thought to be necessary or advisable, a box encasement with removable cover can be constructed in the apex of the V-shaped wall (fig. 19, *A*). The upper side of the box should be made pervious to allow passage of water. A generous amount of gravel and rock should be filled in behind the spring box and collecting wall to allow unrestricted passage of water. The porous material is then covered with soil, and a vegetal cover is established from seed or sod to protect the surface. A layer of burlap

Colo-404

FIGURE 20.—A cheap but effective spring installation similar to that in figure 19, *B*. The man in the far background is standing on the collection gallery, about 300 feet from the drinking trough. Note the overflow pipe and the use of rocks to prevent the formation of mudholes. This installation is satisfactory for small groups of livestock.

between the porous deposit and the soil cover will retard undesirable mixing.

In the development of contact springs for watering livestock the covered box is frequently not used (fig. 19, *B*). This saves some expense, and though the practice is not entirely desirable, ordinarily the spring will function satisfactorily for many years (fig. 20). The V-shaped collecting wall is constructed below the spring outcrop and backfilled with a thick layer of rock, gravel, and sand, which in turn is covered with soil and protective vegetation. The water is piped from the collecting sump thus formed in the porous material to a stock-watering trough or storage tank. If it becomes necessary to clean the spring, it must be dug out and the fill materials replaced.

Where spring water emerges at several widely spaced points, coarse gravel and rock-filled ditches or, preferably, open-jointed tile

embedded in gravel-filled ditches can be used to advantage for collecting water from outlying points, and thus the expense of extending collecting walls long distances into or along the hillside is eliminated. The water from some springs can be collected in tile lines of this type and led directly to a watering trough or tank by means of a properly connected pipe line and the masonry collecting wall eliminated entirely. This is usually one of the simplest and cheapest methods of developing springs.

All springs should be protected from surface run-off, and, except for the open-type development, they should preferably be enclosed by a substantial fence to exclude livestock. A suitable intercepting ditch is desirable to divert surface run-off around the spring. A dense cover of vegetation around the spring will retard erosion damage. The drinking trough should be placed outside the fenced enclosure, where animals will have ready access to it from as many directions as the natural terrain will permit. Rock or gravel should be placed around the trough to prevent the formation of mudholes.

Many people believe that just because water emerges from a spring it is pure. This belief has resulted in gross neglect in adopting sanitary precautions in spring developments. Even springs in isolated sections of the range may be used by the range riders as a source of drinking water and should be reasonably safe for use. Springs can easily become polluted and should therefore be protected from surface contamination. If the water is to be used for domestic purposes it should be analyzed frequently to ascertain possible infection. Underground contamination is also probable, especially in limestone areas, where it is not uncommon for water to flow for many miles in underground channels that may be receiving the discharges from numerous sinkholes.

RESERVOIR INFLOW

For reservoirs of either the excavated or impounding type, surface run-off from the contributing watershed is usually the major source of the water supply. It is of primary importance that the drainage area be large enough to yield sufficient run-off to maintain the water supply in the reservoir during periods of drought and yet not so large as to present unnecessary flood hazards during storm periods or to require large and expensive overflow structures to safely bypass excess run-off. In general, it can be said that reservoirs should be located on or along small tributaries rather than on main streams in order to reduce flood and silting hazards. If the reservoir inflow is not reasonably free from silt or debris, deposition may nullify storage capacity in a very short time. To provide a dependable water supply, it is necessary that the storage depth of the reservoir be sufficient to provide for the seepage and evaporation losses as well as the amount of water consumed by livestock. These essentials must be given adequate consideration during preliminary field investigations, or the reservoir will probably fail to function as intended, and expenditures will be wasted regardless of how carefully the subsequent construction work is carried out. Each proposed reservoir location should be carefully examined to determine the possibility of economically procuring and retaining a satisfactory water supply, and doubtful sites should be abandoned before additional expenditures are incurred.

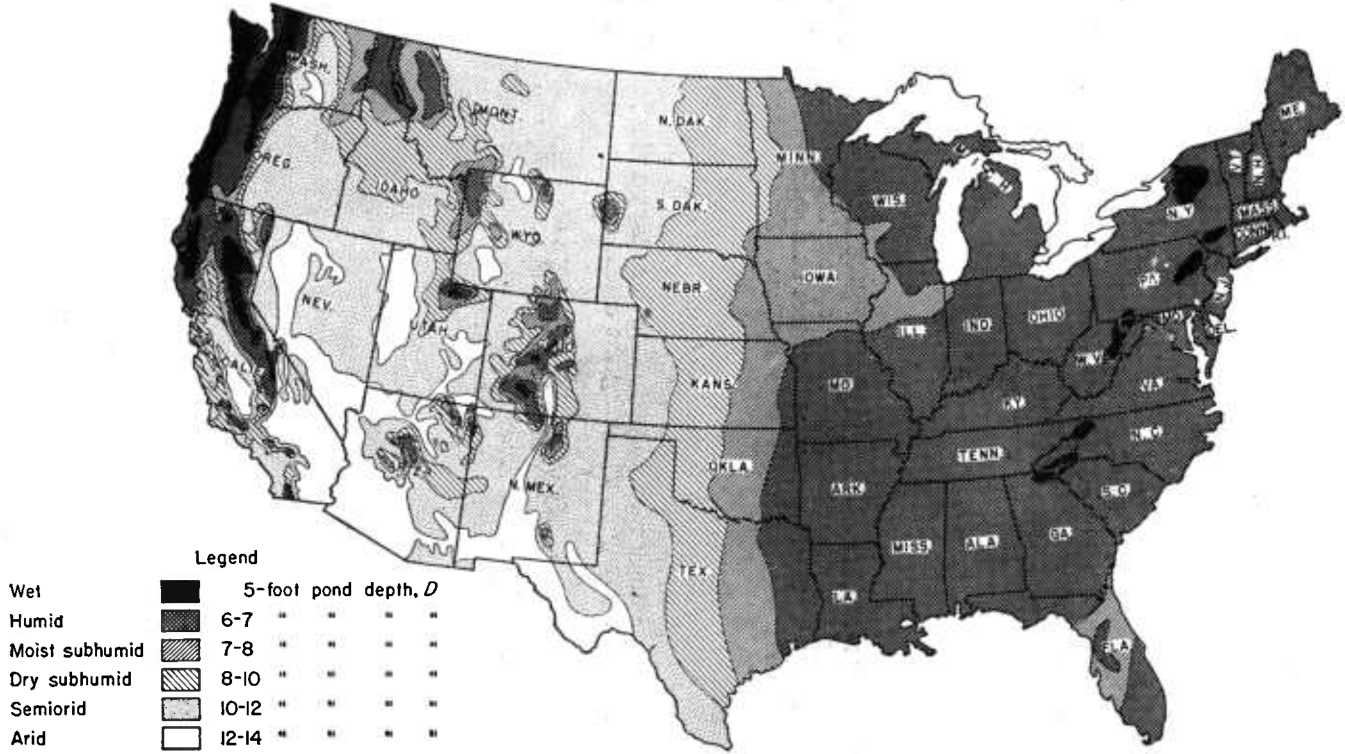

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FIGURE 21.—Recommended minimum depths of reservoirs. An average depth, *D*, should be provided over a pond area sufficient to hold at the designated depth a volume of water that is about twice the amount actually required for the livestock and other supplemental uses. The area delineations are taken from Thornthwaite.

RESERVOIR DEPTH

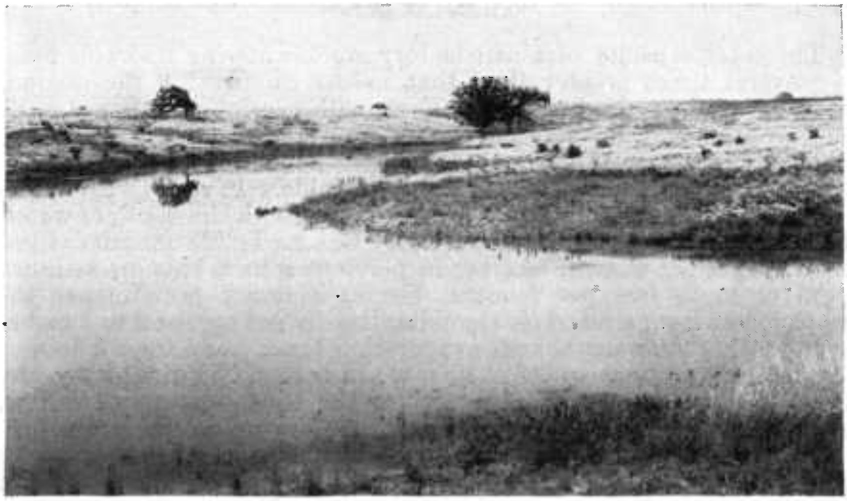
The total capacity of a satisfactory stock-watering reservoir must be several times greater than that needed to provide the amount actually used by the livestock. Even with careful selection of sites, the seepage and evaporation losses from reservoirs are ordinarily much larger than the amount of water beneficially utilized. The seepage from earth reservoirs is highly variable. It varies with watertightness of the soil forming the reservoir and with the depth of water. In heavy, impervious soils, seepage may be a negligible quantity of less than 1 inch per month, whereas in pervious soils it may be as much as 3 or more feet per month. For satisfactory performance the seepage loss from a reservoir should ordinarily not exceed 2 to 3 inches per month. Average annual evaporation losses vary from 3 feet or less in some sections to 6 feet or more in others. During dry years, when the reservoir probably receives the least amount of inflow, evaporation losses are usually greater than during normal years.

To assure a permanent water supply in reservoirs it is necessary to provide sufficient water depth to meet livestock requirements and offset probable seepage and evaporation losses. These losses vary in different sections of the country and also from year to year in any section. They vary also in different types of reservoirs. Figure 21 has been compiled from available data and from field observations to indicate recommended minimum water depths for reservoirs, assuming normal seepage and evaporation losses. In any pond a volume of water that is about twice the amount required for the livestock and supplemental uses should be provided for within an area the average depth of which is that shown in figure 21. It is desirable to provide reservoirs having greater depths wherever feasible, particularly where a permanent or year-round water supply is essential or where seepage losses may exceed a few inches per month.

WATERSHED PROTECTION

To maintain the required depth and capacity of a reservoir, it is necessary that the inflow be reasonably free from silt. The best protection against harmful silting is adequate erosion control on the contributing watershed. An eroding watershed contributes silt to the reservoir during storms and gradually reduces its capacity. Generally speaking, land that is under a permanent cover of vegetation, such as trees or grasses, and is properly protected makes the most desirable drainage area (fig. 22). If such an area is not available, cultivated areas that are protected by necessary conservation practices, such as terracing, contour tillage, strip-cropping, crop rotations, and other soil-improvement practices, should be utilized.

Should it be necessary to utilize an eroding or inadequately protected watershed to supply reservoir inflow, it would be desirable to delay construction of the reservoir until necessary protection can be established on the watershed. In any event, protection of the watershed should at least be begun as soon as reservoir construction is decided upon. Even watersheds used for pasture and range require grazing control and other forage-improvement practices. It is important that erosion be checked in gullies, particularly in those that discharge directly into the reservoir.



Mo-626B

FIGURE 22.—This drainage area, well-protected with a permanent cover of grasses, contributes a minimum of silt to the reservoir.

In addition to providing regular watershed protection, it is often desirable to establish and maintain one or more desilting areas immediately above the reservoir. A desilting area is a long band of dense vegetation through which the run-off must flow before entering the reservoir (fig. 23). Desilting areas should be wide enough to extend between high-water lines on each side of the draw leading into the reservoir and may vary in length from 100 feet to 1 mile or more. Dense-growing shrubs or woody plants are particularly effective in desilting areas because of their ability to retard the velocity of water and cause silt deposition. If the inflow channel above the reservoir is wide and shallow, dense grass covers will cause silt deposition. Livestock should be excluded from these desilting areas.

Locating a reservoir so that its inflow is supplied by means of one or more diversion ditches or terraces is also an effective way of protecting the reservoir if the ditches and terraces are adequately protected and maintained. By means of diversion ditches it is also possible to divert from a stream part of its flood flow. By thus allowing the main volume of water to continue in the stream channel, most of the silt-laden water will be bypassed. Such an arrangement also reduces flood hazards to the reservoir, since inflow will be limited by the capacity of the diversion ditch.

Some protection against silting can also be had by constructing one or more settling basins above the reservoir. A method sometimes used in the Southwest for decreasing silt accumulation in dugouts is to construct a basin-forming dike a short distance above the dugout. The dike is made high enough and long enough to catch most of the flash run-off from the contributing drainage area. A large pipe or flume is placed from the dike to the dugout. The basin acts as a clarifier to desilt inrushing waters. One or both ends of the dike must be so located that they will act as spillways to discharge excess run-off. Ordinarily, mechanical desilting basins of this type should

be considered only as a last resort because of the renewal work necessary as these basins fill with silt. Their use should be limited to areas where adequate protective measures cannot be maintained on the watershed or to the period when the protective measures are being established.

WATERSHED SIZE

The amount of run-off from a given drainage area is dependent on so many interrelated factors that no set rule can be given for its determination. Watershed characteristics, such as slope, shape, size, cover, or soil, and the storm characteristics, such as amount, intensity, duration, or occurrence of rainfall, have a direct effect on the annual yield from any area. General speaking, storms of high intensity or areas of high annual rainfall produce a relatively greater amount of run-off than do low-intensity storms or areas of low annual rainfall. Other things being equal, a drainage area of steep slope, poor cover, or impervious soil will contribute a greater amount of run-off than one of moderate slope, good cover, or pervious soil (fig. 24). This explains why frequently a farm pond the drainage area for which heads into a sharp, steep escarpment may receive ample run-off from only a small drainage area, whereas another nearby pond with a much larger drainage area composed of relatively flat land may be nearly dry. Drainage areas in the more humid sections produce a greater average annual run-off than areas of similar size and characteristics in arid or semiarid sections.

In the Northern States, particularly in the Northwest, where run-off from melting snow often furnishes the largest proportion of the reser-

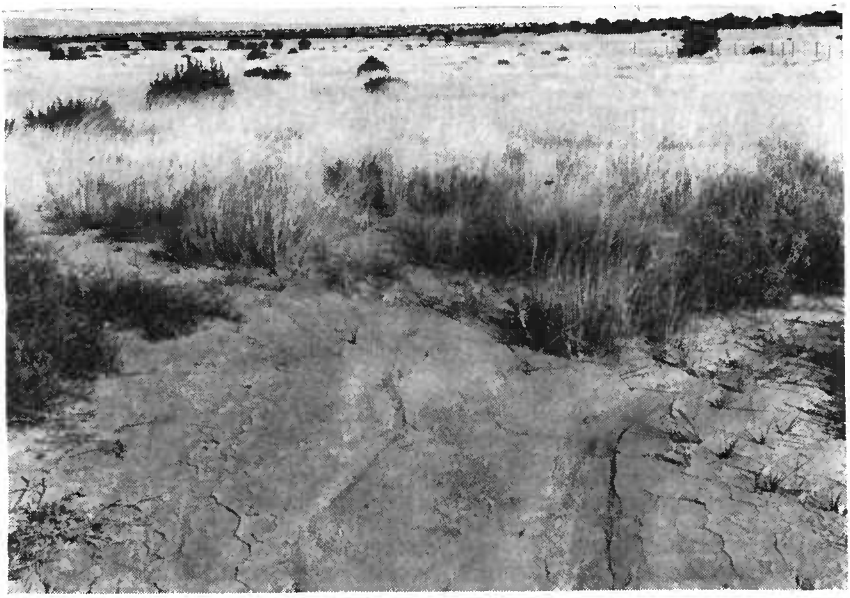


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FIGURE 23.—Silt deposition within a desilting area. One boundary of the area is marked by the fence on the right. The reservoir is in the background. This desilting area is nearly one-half mile long and about one-quarter mile wide.

voir water supply, the topography of a watershed has a direct effect on the amount of run-off from the snow. Watersheds with narrow, deep valleys at right angles to prevailing winds or those covered with trees, shrubs, and other obstructions tend to retain a greater amount of snow to produce spring run-off than a flat, open type of watershed, where most of the snowfall is blown away. Since snow is one of the

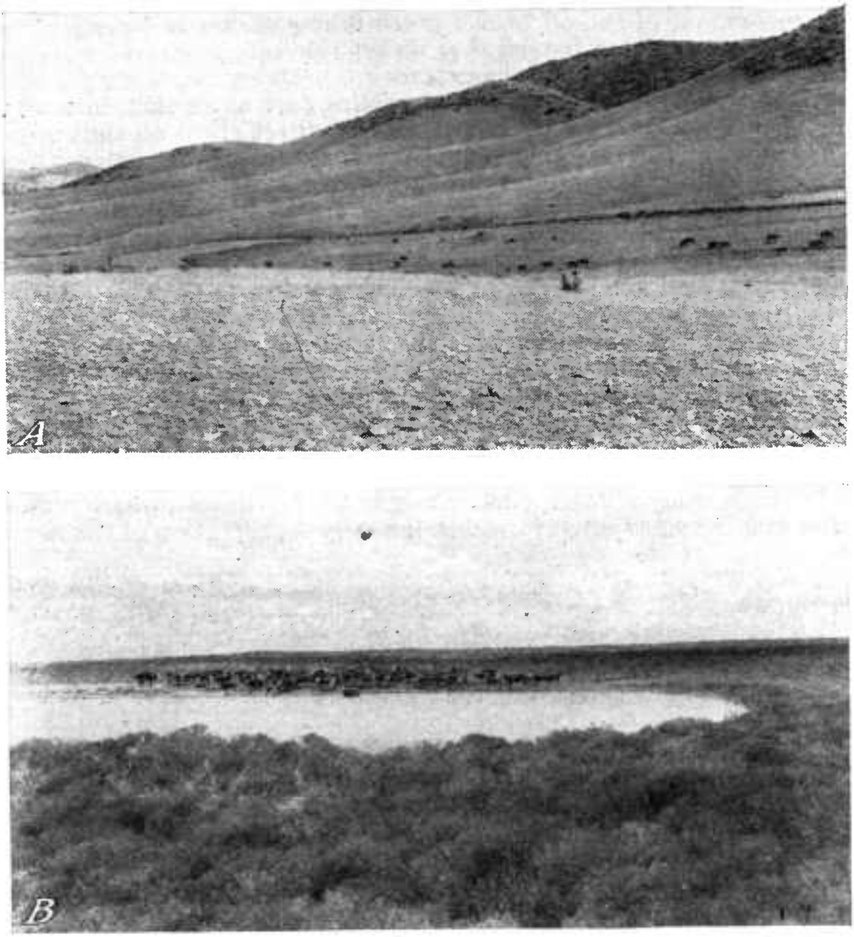

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FIGURE 24.—*A*, The steep slopes and relatively poor cover on this drainage area are conducive to both large amounts and high rates of run-off. *B*, This drainage area is gently sloping, and the cover, though not luxuriant, can be classified as fair. Under like conditions of rainfall the run-off from this drainage area will be less than that from an equal area of the type shown in *A*.

most dependable sources of reservoir supply in the Northern semiarid sections, watersheds that tend to retain considerable snow should be given priority over watersheds that do not retain snowfall. Where necessary, artificial measures for retaining snow, such as snow fences and snow ridging, can be used to advantage to collect additional snow on watersheds that ordinarily would not otherwise produce sufficient run-off to fill reservoirs.

In areas where the rainfall distribution is spotty, particularly in the arid and semiarid sections, the yield from watersheds in the same vicinity may differ greatly. For example, it has frequently happened that one of two similar reservoirs only a short distance apart consistently fills with water and the other fills only occasionally. This will occur despite the fact that the reservoir that failed to fill may have an even larger drainage area than the other. It can be accounted for partly by the fact that rains seem to occur on certain areas more consistently than on others. Such local peculiarities, if known, should be considered in deciding the minimum area of watershed required.

Through a study of past records of performance of various watersheds it is possible, with these as a guide, to estimate the probable run-off from similar watersheds under normal conditions. To simplify the amount of investigation otherwise necessary, a chart has been prepared to serve as a general guide in estimating the approximate size of the drainage area required for a desired water storage (fig. 25). For example, a reservoir having a capacity of 5 acre-feet of water, if located in west central Kansas, would require a drainage area of at least 175 acres under normal conditions. All reservoirs should meet the depth requirements given in figure 21.

The chart has been compiled from field observations of existing farm ponds and from average annual rainfall and run-off information, with adjustments made to provide for drought periods and to give reasonable assurance of an adequate water supply. It is to be used only as a general guide in design. In order to apply information on the chart certain adjustments may be necessary to provide for local conditions. Reliable local run-off information that may be available should be used in preference to the chart. It is often possible to get valuable design information by studying the performance of reservoirs that have been in operation for a number of years in the vicinity in which the new reservoir is to be built.

The chart is based on average physical conditions in the areas shown. These conditions are assumed to be normal run-off-producing characteristics for the drainage area, such as moderate ground slopes within the range of 5 to 10 percent, normal soil infiltration, fair vegetal cover, and normal surface storage. These characteristics have been described in table 2. A description of extreme, high, and low run-off-producing characteristics is also included in the table. It is intended that the characteristics be considered only as they affect surface run-off from the drainage area and not total run-off. Infiltrated water that may enter the reservoir as ground-water flow has not been considered.

For drainage areas having run-off-producing characteristics other than normal the numbers in figure 25 should be modified. Since it is not possible to estimate exactly to what extent the individual characteristics will affect the amount of run-off from a drainage area, only approximate values can be given. It is suggested that for drainage areas having extreme run-off-producing characteristics the numbers in figure 25 be reduced by as much as 25 percent and that for low run-off-producing characteristics they be increased by as much as 50 percent. Even greater changes may be made if conditions indicate that the suggested changes are insufficient. Before large changes are made in the numbers in figure 25, the probable yield of water from the drainage area should be carefully investigated.

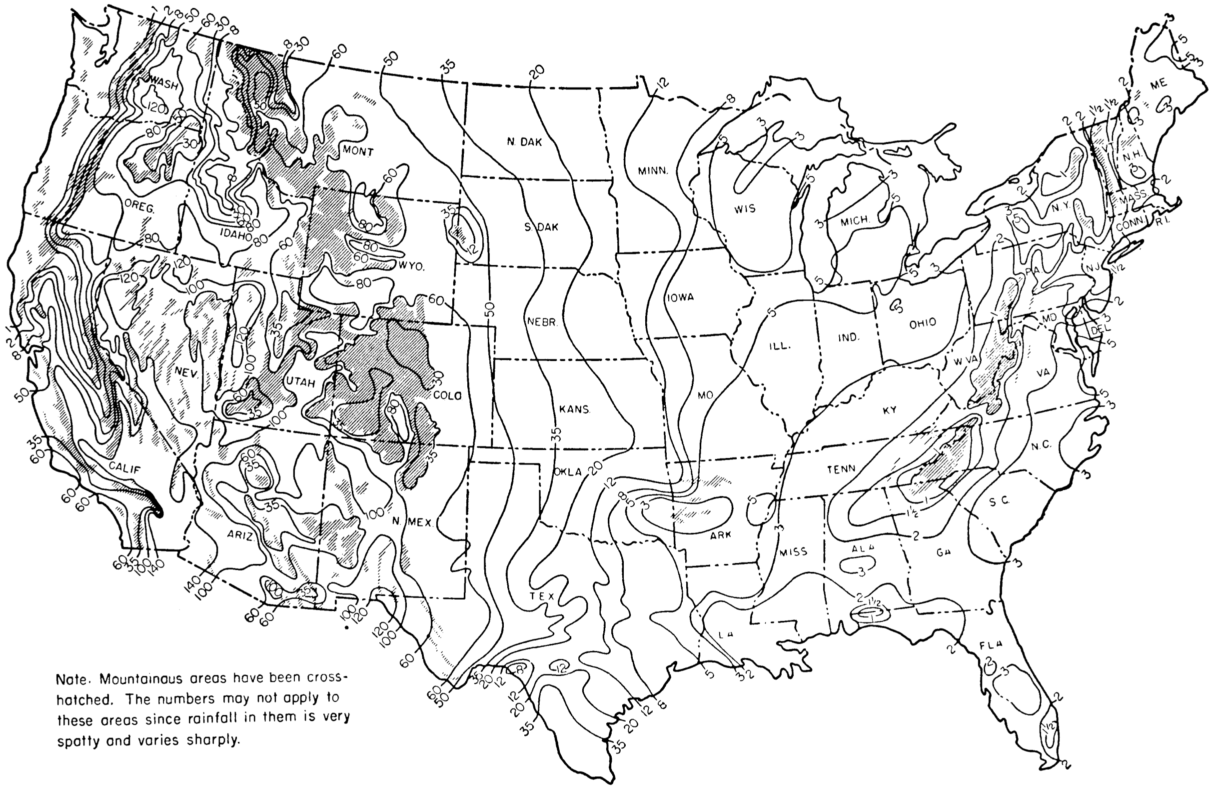

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FIGURE 25.—A general guide for use in estimating the approximate size of drainage area required for a desired storage capacity in either excavated or impounding reservoirs. The numbers on the chart show the number of acres of drainage area required for 1 acre-foot of water impounded.

It is seldom that a drainage area will have all the characteristics falling under one of the types—extreme, high, normal, or low. It will usually be necessary to estimate the extent of variation from such a type and modify the numbers accordingly. For example, suppose a drainage area has rolling terrain with slopes about 8 percent, a deep prairie soil, poor vegetal cover, a large percentage of the land in clean-cultivated crops, and low surface storage. Such a drainage area has run-off-producing characteristics that probably fall between high and normal (table 2). The reduction to the numbers in figure 25 may be anywhere between 0 and 25 percent, depending on which of the characteristics has the greatest influence on surface run-off from the drainage area. It is felt that only in extreme cases should a full 25-percent reduction be made; otherwise conservative design will not be obtained.

TABLE 2.—*Run-off-producing characteristics of watersheds* [1]

Designation of watershed characteristics	Run-off-producing characteristics			
	Relief	Soil infiltration	Vegetal cover	Surface storage
Extreme	Steep, rugged terrain, with average slopes generally above 30 percent.	No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity.	No effective plant cover; bare or very sparse cover.	Negligible; surface depressions few and shallow; drainageways steep and small; no ponds or marshes.
High	Hilly, with average slopes of 10 to 30 percent.	Slow to take up water; clay or other soil of low infiltration capacity, such as heavy gumbo.	Poor to fair; clean-cultivated crops or poor natural cover; less than 10 percent of drainage area under good cover.	Low; well-defined system of small drainageways; no ponds or marshes.
Normal	Rolling, with average slopes of 5 to 10 percent.	Normal; deep loam with infiltration about equal to that of typical prairie soils.	Fair to good; about 50 percent of drainage area in good grassland, woodland, or equivalent cover; not more than 50 percent of area in clean-cultivated crops.	Normal; considerable surface-depression storage; drainage system similar to that of typical prairie lands; lakes, ponds, and marshes less than 2 percent of drainage area.
Low	Relatively flat land, with average slopes of 0 to 5 percent.	High; deep sand or other soil that takes up water readily and rapidly.	Good to excellent; about 90 percent of drainage area in good grassland, woodland, or equivalent cover.	High; surface-depression storage high; drainage system not sharply defined; large flood-plain storage or a large number of lakes, ponds, or marshes.

[1] This table is designed primarily for use in estimating surface run-off and not as a basis for estimating total run-off.

If a drainage area has low run-off-producing characteristics such as ground slopes of about 1 percent, a very porous and deep soil, excellent grass cover, and a large number of depressions for surface storage of water, the numbers in figure 25 should be increased considerably, the amount of increase being an estimate of the effects of these characteristics on surface run-off from the drainage area.

Good judgment must be exercised in applying figure 25 to actual field use. Field investigation should dictate whether the values included apply directly or require modification. The chart is intended primarily for drainage areas up to 7 or 8 square miles. Since in mountainous areas wide variation in rainfall occurs within relatively short distances and since the rainfall distribution there is extremely spotty, these areas have been shaded to indicate high variability.

The ratio lines may not apply to these areas, and information for installations within them should be based on local field investigations.

Consideration should also be given to the permanency of the conditions of a drainage area. It is possible that future changes in land use may materially affect run-off from a drainage area. For example, certain changes in land use may so reduce the run-off that the drainage area will no longer keep the pond supplied with water. Also, where the drainage area utilized extends into adjacent farm or ranch units, the possibility should be considered that the run-off from these parts of the drainage area may in the future be diverted or retained for use in the area of origin. In selecting a proper ratio of drainage area to impounded capacity the ratio should be based on the expected land use over the entire watershed. This is particularly important on eroding watersheds where protective measures such as complete vegetal covers are to be installed to provide necessary pond protection.

RATE OF RUN-OFF

The largest percentage of failures in small reservoirs of the impounding type is due to inadequate spillway capacity or protection. Besides being protected from erosion damage, spillways must have sufficient capacity to bypass run-off at the maximum rates ordinarily expected from the contributing drainage area, or overtopping is likely to destroy the dam (fig. 26). For small reservoirs the total amount of run-off that may be discharged from a watershed for a single rain or a definite season is of little significance in determining the size of spillway required. The reservoir may fill in a short time during a heavy storm, and the spillway must therefore be large enough to bypass subsequent run-off.

If the reservoir is large and the drainage area relatively small in comparison, the storage capacity of the reservoir may be sufficient to take care of all run-off from the drainage area. However, in the construction of farm ponds it is conservative practice to assume that the reservoir is full of water at the beginning of a storm and that the spillway must be large enough to handle the maximum rate of run-off resulting from that storm. It is assumed, of course, that the storm is of a magnitude falling within the storm frequency or occurrence for which the spillway is designed. It is felt that spillway capacity sufficient to carry the peak flow from storms of 25-year occurrence is sufficient for ordinary farm-pond construction if the cost of the impounding structure is relatively low. For high-cost structures, and those whose failure would endanger property, storm occurrence of 50 years or more should be used. Such structures would be the exception rather than the rule. For small, inexpensive structures a design for storms of 10-year occurrence is generally sufficient.

Both rainfall and watershed characteristics have a marked influence on the rate of run-off that can be expected. With other factors constant, high rainfall intensities, steep slopes, poor covers, impervious soils, or short watersheds tend to produce higher rates of run-off than low rainfall intensities, flat slopes, good covers, pervious soils, or long watersheds (fig. 24). The maximum rate of run-off from any specific watershed usually occurs when rains of high intensities fall on saturated or frozen soil or during periods when vegetal cover is depleted or dormant. Since the washes, draws, or arroyos that oridinarily

supply the run-off for stock-water reservoirs are dry during most of the year and barren of cover, the force and volume of storm waters coming from them are commonly underestimated.

Determining the capacity for which spillways should be designed is a difficult problem owing to the variety of run-off conditions. Local information on the rates of run-off from various watersheds should be utilized to the fullest extent. Reliable records of run-off rates from similar watersheds in the same vicinity form a valuable guide. Run-off observations or high-water marks immediately above the dam site often are a good source of information. If high-water marks are discernible, the average cross-sectional area of the

Okla-5496

FIGURE 26.—An adequate spillway was not provided for the dam, and excess water is flowing over the top of the fill. Severe cutting is already under way.

channel can be estimated and a spillway with a larger cross-sectional area provided in order to assure a margin of safety. If possible, an engineer or someone experienced in estimating run-off rates should be consulted.

Figures 27 and 28 have been prepared for use as a guide in estimating run-off rates from various drainage areas. These charts may be used directly if other information is not available or as a supplement to such local information as may be available.

The procedure for estimating flood flows given in this bulletin is an adaptation of an unpublished method developed by H. L. Cook, of the Hydrologic Division, Soil Conservation Service.

Good judgment must be exercised in using these charts. Figure 27 indicates the rate of run-off that may be expected from drainage areas of various sizes for storms occurring theoretically on an average of about once every 25 years. In the upper left-hand corner of the

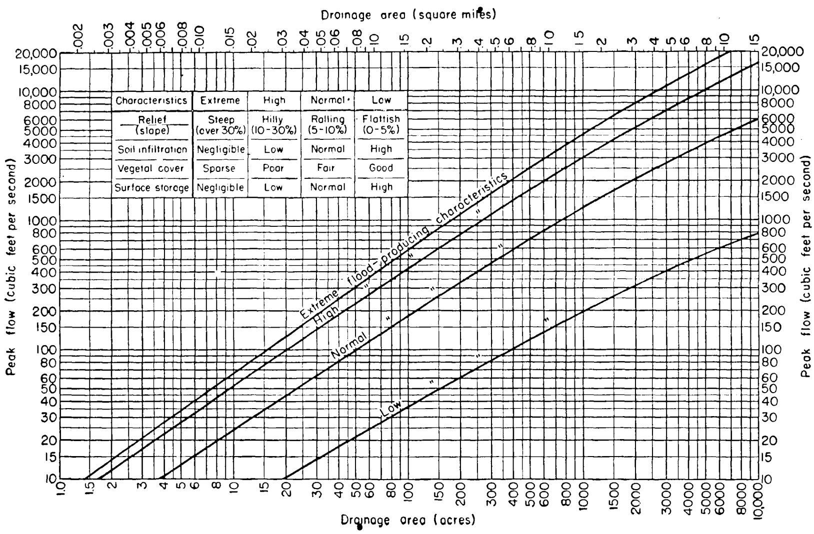

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FIGURE 27.—Rate of run-off (rainfall factor of 1) from storms of 25-year occurrence and various watershed characteristics. Watersheds are assumed to be about as wide as they are long. When designing reservoirs for storms of 10-year occurrence, reduce the rate of run-off by about 15 percent, and for storms of 50-year occurrence increase it about 20 percent.

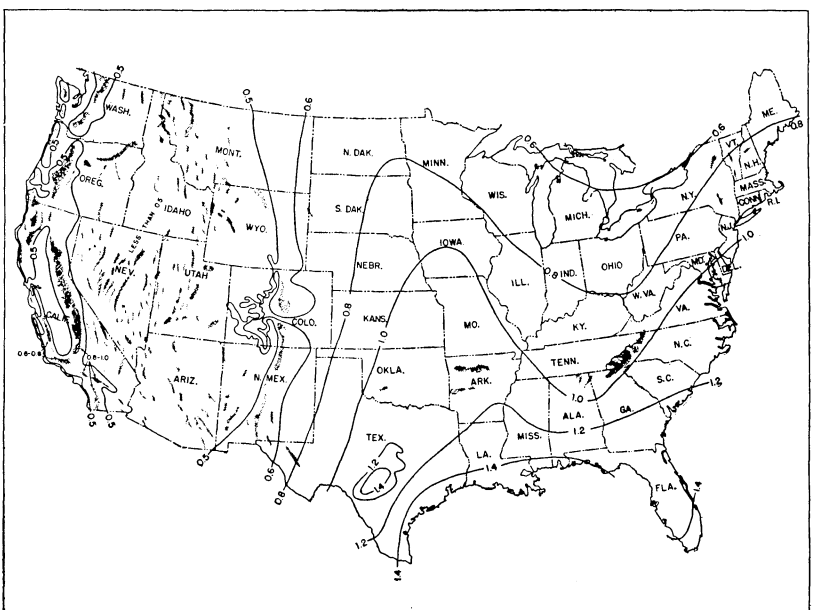

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FIGURE 28.—Distribution of rainfall factors to be used with figure 27 in adjusting run-off rates. The curves in figure 27 are based on a rainfall factor of 1. In cross-hatched areas the rainfall is more intense than in the surrounding country. If the range of rainfall factors for these areas is not indicated on the map, use a factor 0.1 to 0.2 higher than the value applicable to the surrounding area. Boundaries of the areas are only roughly indicated.

chart is a summary of the various flood-producing characteristics represented by the four curves on the chart. Table 2 gives a detailed description of watershed characteristics.

For design purposes the rate of run-off should be selected from the curve in figure 27 that most nearly fits the drainage area in question. Since the curves are based on a rainfall factor of 1 shown in figure 28, it will be necessary to make further adjustment to run-off rates from drainage areas having other rainfall factors. These adjustments can be made according to the rainfall factor representative of the geographic location of the drainage area.

To find the probable run-off rate from a 200-acre drainage area located in eastern Wyoming the following factors would need to be taken into consideration. The area is hilly, with slopes of about 20 percent. The soil is heavy gumbo. Vegetal cover is poor, and surface storage of water is low. In all probability this drainage area could be classified as having high flood-producing characteristics (table 2 and fig. 27). The rate of run-off as read from the proper curve would be about 750 cubic feet per second. The curves in figure 27 are based on a rainfall factor of 1, and since eastern Wyoming would have a rainfall factor of about 0.6 (fig. 28) we would have an adjusted run-off rate of 0.6×750, or 450 cubic feet per second.

The sample problems on pages 48 and 64 indicate the steps to be followed in using the information given in figures 25, 27, and 28 and in table 2.

EXCAVATED RESERVOIRS[2]

An excavated reservoir is one of the simplest types of reservoirs to construct and the only type of earth reservoir that can be constructed economically in relatively flat terrain. The fact that the capacity of these reservoirs is secured by excavation limits their practical size, and they are best suited to locations where a comparatively small reservoir supply is sufficient and where impervious soil conditions prevail. Since they expose a minimum amount of surface area in proportion to their volume, they are advantageous in areas where evaporation losses are high and water scarce. Under such conditions their use enables livestock to utilize a greater part of the available water. The ease with which they can be constructed, their compactness, their safety from flood-flow damage, their flexibility of location, and their low maintenance requirements make their use popular in some sections. The difficulty of getting the water out of the reservoir and of getting livestock to it are two of their chief disadvantages.

To function satisfactorily, excavated reservoirs must be properly constructed and located. They must have sufficient depth and volume to provide the necessary water supply. They must be located in an impervious soil; otherwise expensive artificial linings will be necessary to prevent excessive losses by seepage. The drainage area must be large enough to maintain the required water supply, and it must be adequately protected to prevent undesirable silt accumulation in the reservoir. If the reservoir is not located in a well-defined draw, diversion ditches will usually be necessary to divert run-off into the reservoir. Once constructed, the reservoir must be protected and maintained.

[2] Excavated reservoirs include dugouts, charcos, tanks, and water holes, and these terms mean one and the same thing. In the Southwest the terms "charco" and "tank" are commonly used; in the North the term "dugout" is popular. "Water hole" is used throughout the West.

SELECTION OF SITES

The grazing and watering requirements of a pasture or range will determine the general location of most stock-water reservoirs. These have been discussed in a previous section of this bulletin. The general location of reservoirs serving other purposes or even those serving supplemental uses must be adjusted according to the purpose of the water supply. For example, if the water supply is needed on the farmstead, the reservoir should be located as close as possible to the source of need. Location should also be such that the water supply will not be contaminated. Drainage from farmsteads, corrals, feeding yards, and other areas where livestock concentrate is likely to be polluted.

An adequate depth of impervious soil is essential for excavated reservoirs. They cannot be used in some sections because of unfavorable soil conditions. If there is any doubt as to the nature of the soil, numerous test holes should be bored over the proposed reservoir area to determine the suitability of the soil and particularly the permeability of the subsoil strata. Sites with porous soils or with underlying strata of sand, gravel, limestone, and other porous materials should not be selected unless such strata are not of sufficient magnitude to cause trouble. Sites with heavy clay, clay loam, or other clay mixtures that extend well below the proposed reservoir depth are desirable.

The performance of dugouts or other excavations in the locality of the proposed reservoir and in a soil of similar type is the best indicator of the suitability of a soil. Where there is no opportunity for studying the performance of existing excavations, some indication of the permeability of the soil can be obtained by filling test holes with water or by forming suitable containers from samples of the soil and filling them with water. The holes or containers may be filled several times or puddled if necessary to represent conditions at a reservoir site. Observations of seepage will indicate what may be expected with a larger reservoir in the same material.

The fact that a reservoir may lose considerable water by seepage immediately after excavation does not necessarily mean that it will be an unsatisfactory reservoir. Frequently new reservoirs do not retain water satisfactorily until they become sealed. This may require several months or even a year or more, depending on the soil type and opportunity for the reservoir to become sealed. Natural puddling of the reservoir, soil saturation, and sediment deposition tend to seal reservoirs that are somewhat pervious. Sealing may be hastened or excessive seepage checked by the trampling of livestock. Forcing livestock to "mill around" in a partly filled reservoir several hours a day packs or puddles the surface and checks seepage. A temporary fence may be necessary to hold livestock in the reservoir during the trampling and sealing process.

Dugouts may be located on areas of almost any type of topography. They are, however, most satisfactory and most commonly used in sections with comparatively flat but well-drained terrain. A site may be selected in a broad natural drainageway (fig. 29) or to either side of a drainageway if the run-off can be diverted into the reservoir. Flat slopes facilitate maximum storage capacity with minimum excavation. The low point in a natural pot hole is often a good location

for a dugout. After the dugout is filled, overflow waters escape through regular drainageways, so locations with favorable discharge conditions should be selected. Floodwaters are less likely to damage dugouts in flat terrain because the overflow spreads out, and scouring or the development of harmful overfalls is less likely to occur. Dugouts should not be located in wet or muddy areas because it will be difficult for livestock to get to the water supply.

Okla-6161

FIGURE 29.—A small dugout in a broad, shallow drainageway. Note the contour furrows in the pasture that aid in producing vegetal cover through moisture conservation.

EXCAVATION

Excavation is the principal work required in dugout construction. Dugouts may be circular, rectangular, or any other shape. Custom, excavation equipment, and natural ground relief commonly determine the shapes used. The rectangular dugout lends itself readily to the use of slip scrapers and is therefore a popular shape. Table 3 gives the approximate amount of excavation in cubic yards for rectangular reservoirs of various sizes. On flat areas the amount of excavation required is practically equivalent to the capacity of the reservoir. On sloping areas the amount of excavation required is usually greater than the reservoir capacity unless part of the excavated material is used to create impounding capacity. If this is done, the special precautions and provisions discussed under Impounding Reservoirs are usually necessary to bypass floodwater.

Figure 30, *A*, gives specifications commonly used for small rectangular dugouts. For larger dugouts the length, width, or depth may be increased, but the side slopes should be about the same. All sides should be sloped sufficiently to prevent sloughing (usually 2 : 1 or flatter), and one or more relatively flat side slopes (4 : 1 or flatter) should be provided for livestock entrances. With certain types of equipment these flatter sides slopes are also necessary to facilitate excavation. It is desirable to proportion dugout dimensions so that

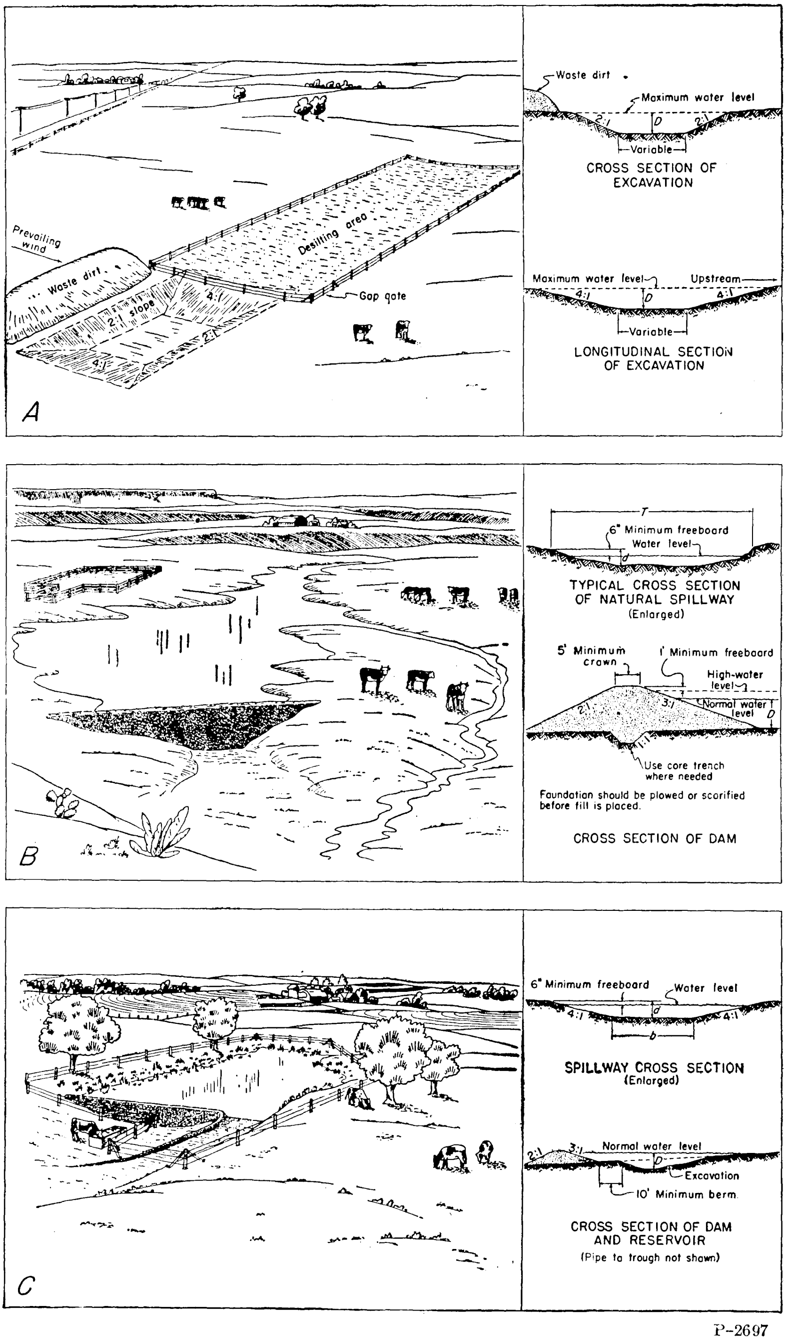

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FIGURE 30.—*A*, Specifications commonly used for small rectangular dugouts. Note the desilting area used with the dugout. Desilting is desirable in areas where considerable silt is carried in the run-off. *B*, A stock pond common in the West. Wherever possible, a natural spillway should be utilized. *C*, A stock pond common in the East. Note the wide entrance to the vegetated spillway.

the maximum reservoir depth extends over as large an area of the reservoir as possible.

TABLE 3.—*Size and approximate capacity of rectangular dugouts with 2 : 1 side slopes and 4 : 1 end slopes*

Top dimensions (feet)	Depth D (feet)	Capacity			
		Cubic yards	Acre-feet	Gallons	Million gallons
50×75	6	452.0	0.28	91,292	0.09
	7	472.6	.29	95,444	.10
	8	483.7	.30	97,703	.10
	9	488.0	.30	98,563	.10
60×100	7	892.6	.55	180,273	.18
	8	937.1	.58	189,264	.19
	9	968.0	.60	195,510	.20
	10	987.7	.61	199,482	.20
65×105	8	1,110.4	.69	224,273	.22
	9	1,153.0	.71	232,875	.23
	10	1,182.1	.73	238,755	.24
	11	1,200.1	.74	242,383	.24
75×125	8	1,676.3	1.04	338,567	.34
	10	1,830.3	1.13	369,671	.37
	12	1,916.0	1.19	386,981	.39
	14	1,952.6	1.21	394,364	.39
90×155	8	2,747.4	1.70	554,896	.55
	10	3,080.3	1.91	622,138	.62
	12	3,309.3	2.05	668,398	.67
	14	3,453.6	2.14	697,542	.70
	16	3,532.3	2.19	713,430	.71
105×185	8	4,085.1	2.53	825,092	.83
	10	4,663.7	2.89	941,937	.94
	12	5,102.7	3.16	1,030,603	1.03
	14	5,421.4	3.36	1,094,973	1.09
	16	5,639.0	3.50	1,138,929	1.14

The wasted earth should not be spread or dumped haphazardly about, but should be placed in uniformly sloped dumps. This will improve the appearance of the dugout and facilitate subsequent revegetation. In the northern Plains the dumps can be placed on the windward side of the dugout to serve as a snow fence for collecting drifts in the dugout (fig. 30, *A*). Dumps in this location may also cut down evaporation losses by breaking the force of the prevailing winds across the reservoir. The excavated earth may sometimes be advantageously used in filling nearby low areas or in the construction of roads. It is sometimes possible to construct dugouts at little or no expense through cooperative efforts with State highway departments or highway contractors. Dugouts adjacent to highways can be excavated advantageously during road construction to secure fill material, and they provide a reservoir into which run-off waters can be diverted from the highway.

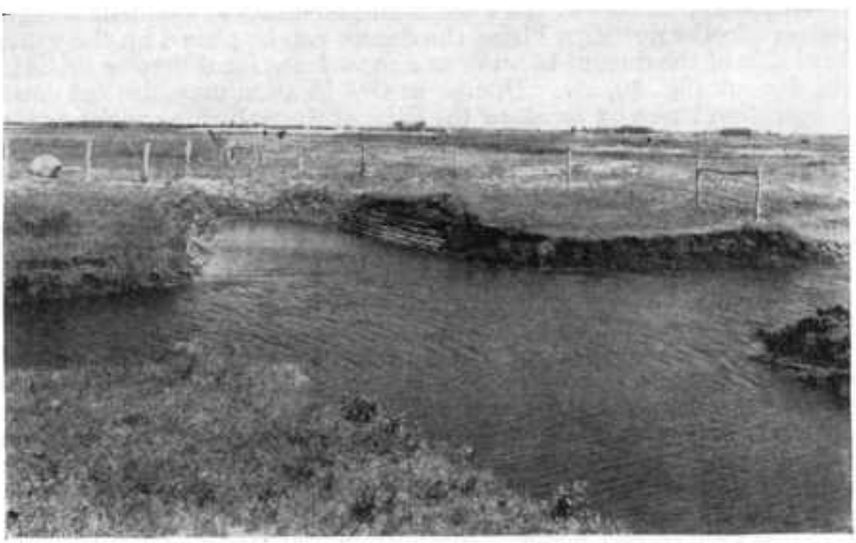
If a large number of dugouts are to be constructed, heavy equipment such as draglines, power shovels, or bulldozers can sometimes be used to advantage. These are usually obtained on a cooperative, contract, or rental basis. The excavating is commonly done with scrapers pulled by team or tractor. Horses, mules, or a small tractor are available on most farms and ranches. If it is possible to borrow or rent suitable scraper equipment of the drag, wheeled, or fresno type from the local county highway commission, or other source, it may not be necessary to purchase or own this equipment. There is little overhead connected with this type of excavating equipment, but it does not have so much capacity as large power equipment. To offset the lower

capacity one owner may operate several outfits, or he may get help from his neighbors. With a tractor the rotary or the wheel scraper is commonly used, and the slip or fresno scraper is usually used with horses or mules. Under favorable conditions and steady operation these can be used to excavate good-sized dugouts.

If light excavating equipment is employed, it is often necessary on hard, dry soils to plow previous to excavating. It is best to plow only one furrow depth at a time and to remove the loosened dirt before plowing more. The whole width of the dugout should be worked down together. Lengthwise the dugout should be deepened to nearly its finished depth, at one end, and after that the scrapers may be filled pulling downhill instead of up. Dugouts excavated with a scraper are sometimes made in the form of a cross to minimize length of haul. This method, illustrated in figure 31, provides entrance at all four sides.

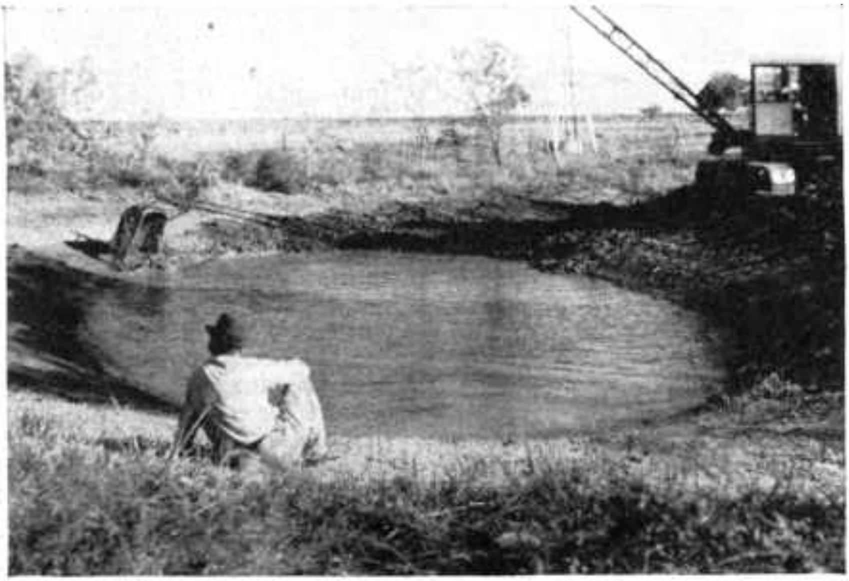
With team and drag scraper it should be possible to move from 30 to 40 cubic yards of dirt during a 10-hour day if the haul is short and other excavating conditions normal. A tractor and wheel or rotary scraper should move considerably more earth per day than a team and drag scraper. The cost per cubic yard of excavation is dependent on such factors as soil type, condition of soil, length of haul, depth of excavation, equipment used, efficiency of the operator, and wages paid. Average excavation work with ordinary farm or ranch equipment should be estimated at 10 to 15 cents per cubic yard. When excavation is difficult these costs may be exceeded somewhat.

Draglines (fig. 32) are sometimes used for dugout construction. A dragline involves considerable overhead expense and is a piece of equipment that few farmers can operate or afford to buy. If sufficient work is available, a local contractor may contract to excavate reser-



ND-302B

FIGURE 31.—A dugout excavated in the shape of a cross. This dugout has a maximum depth of about 12 feet.



Tex-100206

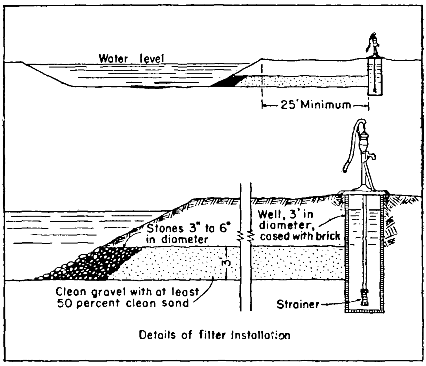
FIGURE 32.—A dragline being used to excavate a small dugout. It can readily be used for wet excavation.

voirs at a fixed rate per cubic yard, or a dragline may be obtained by purchase or rental on a community basis. Farmers' organizations may obtain and operate the equipment and do excavation work for farmers at cost. With efficient dragline operation, dugout excavation may cost as little as 7 or 8 cents per cubic yard, and the excavation can be done more quickly than with smaller equipment. It is also easier to get adequate reservoir depth with this method of excavation. A dragline can be operated when the ground is muddy, whereas scrapers cannot. If the required excavation work is at widely scattered points, the difficulty and expense of transporting a dragline may make its use impractical.

If available, large tractors, with wheeled scrapers or bulldozers and power shovels, can be used for dugout construction. The bulldozer is used to construct a dugout by pushing the dirt out at each end, and a shovel is usually used in connection with dump wagons or trucks. When necessary, blasting powder can be used alone or in conjunction with other methods to excavate dugouts. The advice of trained men should be obtained for excavating by blasting.

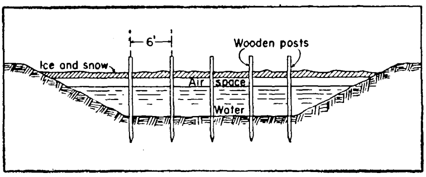
FILTER WELLS AND FROST PROTECTION

If it is desired to exclude livestock from the dugout and obtain a yield of clean water, the dugout should be fenced and some method used to filter the water. A successful method has been to sink a filter well beside the dugout (fig. 33). Several different types of filters may be used. The type shown in figure 33 requires the digging of a trench about 2 to 3 feet wide from the side of the dugout for a distance of 30 to 40 feet or more. At the end of the trench an ordinary wellhole



O–2964

FIGURE 33.—A method of filtering water from a dugout. Water for human consumption should be filtered and disinfected.



O–2964A

FIGURE 34.—Cold-weather protection for a dugout.

is dug, curbed, and fitted with a pump. The trench should be filled with 2 to 3 feet of gravel that contains at least 50 percent of sand. The dugout end of the trench should be covered with heavy gravel and small stones to prevent too rapid clogging of the filter trench.

The use of a water filter such as that shown in figure 33 does not assure safe water for domestic use. Water filtered with such equipment may be used for household washing, but it should not be used for cooking or drinking. Before the contaminated water ordinarily found in small surface reservoirs can safely be used for domestic purposes, it must, in addition to filtration, be treated with a sterilizing agent, such as chlorine, or it should be boiled for at least 20 minutes.

In the North the water in dugouts may freeze to the bottom and thus render the dugout useless. Even in relatively deep reservoirs that ordinarily do not freeze to the bottom the gradual accumulation of snow and the removal of water being used may cause the ice to fall in, thus increasing the likelihood that the remaining water may freeze solid.

To minimize the freezing hazard a unique method has been suggested by the agricultural engineering department of the Manitoba Agricultural College. This method is shown in figure 34. It consists of cutting holes in the ice after it has frozen to about an 8-inch thickness. The holes should be spaced about 6 feet apart. Posts are then driven through the holes and into the mud bottom far enough to give some support. The water will freeze around the posts, and as water is withdrawn they will act as columns to support the ice sheet, leaving an air space between the water surface and the ice. The air space acts as an insulator and thus reduces further freezing considerably.

SAMPLE PROBLEM

To familiarize the reader with the design information on excavated reservoirs that has been give in the preceding discussion a sample problem is given. The problem is representative of conditions on the northern Great Plains.

A farmer in western North Dakota desires to construct a dugout. He has 100 head of cattle and 200 head of sheep to water and wishes one-half year's supply. An available drainage area consists of 200 acres of flattish prairie land with good vegetal cover. The average slope of this drainage area is about 3 percent. The soil is a typical

prairie soil, and infiltration would probably be classified as normal. Surface storage of water is normal.

From figure 3 we find that 100 head of cattle require about 1.4 acre-feet of water and 200 head of sheep between 0.2 and 0.3 acre-feet. Thus about 1 acre-foot of water will be the actual livestock requirement for one-half year. In figure 21 we note that in western North Dakota the recommended minimum depth for reservoirs is about 10 to 12 feet if evaporation and seepage are to be offset. To be conservative, a 12-foot depth is selected for the dugout and a capacity of about twice the livestock requirement of 1 acre-foot, or a total of 2 acre-feet of water. In this way, even though evaporation and seepage losses may amount to 4 or 5 feet of water, the actual stock water requirements of 1 acre-feet will still be available. Table 3 indicates that in order to obtain 2 acre-feet of water capacity with a 12-foot depth a rectangular dugout must have top dimensions of at least 90 x 155 feet. These dimensions are for side slopes of 2:1 and end slopes of 4:1.

From table 2 we note that the watershed run-off characteristics are such as to be classified between low and normal. For western North Dakota, according to figure 25, a ratio of about 35 of drainage area in acres to impounded capacity of reservoir in acre-feet is recommended for normal conditions. Since the slope of the drainage area is only 3 percent and the vegetal cover good, it is conservative design to assume that a larger drainage area than necessary for normal run-off-producing characteristics is required. For this problem an increase of 35 percent over the size of drainage area recommended in figure 25 was selected. Multiplying according to this 35-percent increase gives a final ratio of $1.35\times35=47+$. The farmer should thus have at least 47 acres of drainage area available for every acre-foot of capacity in the reservoir. Actually he has a ratio of $\frac{200}{2}=100$. The available drainage area will therefore probably be large enough to keep the dugout supplied even during drought years.

IMPOUNDING RESERVOIRS

The impounding-type reservoir (fig. 30, *B* and *C*) is usually formed by means of an earth fill across a narrow draw or valley. The borrow pit or excavation from which the material for the earth fill is obtained may be used as part of the reservoir. Wherever feasible, this practice is advantageous in obtaining additional reservoir depth. The impounding reservoir is the most common type of earth reservoir now being used. It is particularly adapted to rolling terrain with well-defined drainage channels and to areas where considerable storage capacity is desired (fig. 35). Ordinarily, it is more expensive to construct an impounding reservoir than an excavated reservoir, and more care and skill are required in selecting suitable sites to bypass floodwater safely and to assure satisfactory construction.

Once the depth of a proposed impounding reservoir has been established, the size or capacity of the reservoir is largely determined by the natural topography at the site selected. The minimum depths recommended for reservoirs in figure 21 will ordinarily give sufficient reservoir capacity to supply livestock requirements. The approximate capacity of a reservoir in acre-feet can be estimated by taking

the surface area of the proposed pond in acres and multiplying by four-tenths of the maximum pond depth[3] in feet. For example, if it is estimated that a reservoir, when full, will cover about 2 acres and have a maximum depth of about 12 feet, the capacity will be about 9 or 10 acre-feet ($0.4 \times 12 \times 2 = 9.6$). This is over 3 million gallons.

11-571

FIGURE 35.—The impounding reservoir is well adapted to rolling terrain. This reservoir has considerable storage capacity. See figure 29.

SELECTION OF SITES

Selecting sites for impounding reservoirs is an important part of the preliminary planning work. To secure economical construction and satisfactory performance one must select a reservoir site that includes a number of favorable features. Time spent in surveying possible sites before making the final selection will usually pay. As with other types of stock-water developments, the grazing and watering requirements of the surrounding area or other supplemental uses will dictate the general location of the reservoir. Contributing drainage areas large enough and well enough protected to produce a satisfactory reservoir inflow, which has been previously discussed, are essential (fig. 25). The reservoir cannot be regarded as a success if either inadequate drainage area or depth produces a dry pond when water is needed.

The impounding reservoir requires a protected spillway to bypass floodwater satisfactorily. The availability of a natural spillway protected with native vegetation is of primary importance in selecting a suitable reservoir site. In the absence of naturally protected spillways, sites on which necessary vegetation can be established should be given priority. For satisfactory results, spillways protected with undisturbed native sod are almost essential in parts of the arid and semiarid West because of the difficulties in reestablishing an adequate cover of vegetation once it has been destroyed. Suitable vegetated spillways must be wide and shallow and must have gentle slopes. A natural swale that will safely bypass the reservoir overflow into an adjacent drainageway makes an ideal spillway. The possibility of diverting reservoir overflow water over a large flat area should not be overlooked. This is not only a simple way to dispose of the reservoir overflow, but it also enables beneficial irrigation of the flooded area.

[3] Maximum pond depth is assumed to be the maximum depth from pond surface to the undisturbed channel bed.

Where natural spillways cannot be provided to bypass flood flows from the contributing drainage area, spillways with mechanical protection are usually necessary. The additional cost of these spillways makes it more difficult to justify the expense of farm reservoir installations. A combination of a mechanical spillway to carry a small portion of the overflow and an auxiliary vegetated spillway to bypass the remainder may be practical where vegetation alone will not provide sufficient protection. Skillful selection of reservoir sites so as to limit the size of drainage areas and utilize favorable local conditions will preclude excessive expenditures and impractical installations.

An important factor to consider in site selection is the stability of the drainageway immediately below the proposed location for the dam. The stability of a structure is dependent on stabilized grades in the channel below. Excessive grades lead to the development of channel overfalls, which gradually advance and undermine structures. The grade for at least several hundred yards downstream from the structure should preferably not exceed 1 percent unless the channel bed contains sufficient rock to prevent harmful scouring or is protected by good vegetal cover.

The amount of fill material that will be required, the nature of the fill material available, the imperviousness of the ponded area, and the suitability of the fill foundation are also important points to consider in the selection of a site. A narrow draw between steep slopes ordinarily produces large reservoir capacity with a small amount of fill material but does not always have satisfactory natural spillways available. Soil suitable for impounding water should be available. If there is any doubt as to the depth of the impervious soil, borings with an auger should be made on the contemplated site. For satisfactory results, porous substrata should be covered with at least 3 feet of impervious clay. Fortunately, the soils on most reservoir sites that are otherwise satisfactory are sufficiently impervious, and satisfactory fill material is usually available. Somewhat pervious reservoirs can usually be sealed adequately by following the same procedure recommended for excavated reservoirs. Wet or seepy sites should be avoided because they usually require special drainage.

The best fill material consists of about two-thirds sand and gravel, well graded, and one-third clay. Such material is stable even with changes in moisture conditions. Fill material with a high clay content, on the contrary, expands when wet, and the contraction that occurs when it dries may open dangerous cracks. Soils high in sand and gravel are pervious and unstable. Satisfactory earth fills can be constructed from soils whose texture varies somewhat from the ideal, but greater precautions should be observed, and some adjustments may be necessary in the construction work. The side slopes of a fill should be made flatter as the sand content in the mixture increases above the ideal. Where two types of fill material are available, they may be mixed to advantage, or it is common practice to place the more impervious soils in the upstream part of the fill and the less pervious soils in the downstream part.

In the absence of laboratory soil-testing facilities the proportions of the available fill material can be approximately estimated by half filling a bottle with a representative sample of the soil. Then fill the bottle with water, shake well to mix, and allow the soil to settle.

Coarse sand will settle out immediately, fine sand within a few minutes, and the silt and clay last. These will stratify into clearly visible layers, from which the approximate proportions of the component parts of the soil can be estimated. A soil test of this type will serve as a valuable guide in determining the suitability of a soil for earth-fill work or in estimating the proportions of different soils that may be mixed to advantage.

SITE PREPARATION

Before any fill material is placed in the proposed dam the site should be cleared of brush, roots, stone, sod, and similar debris. Trees and brush should also be removed from the area that is to be flooded when the reservoir is full. This waste material can be deposited at some convenient location and some of it can be used later for riprap or mulch

ND-51

FIGURE 36.—Core trench for a small earth dam. The sides of the trench have not been sufficiently sloped. The men are laying rock riprap.

on the completed fill. All topsoil and sod stripped from the dam site should be placed in a separate pile so that it will be available for use in covering the fill and unproductive areas in the spillway. Soft or mucky soil should also be removed from the dam site to get a firm foundation.

Any overhanging banks on the site and all pits or holes should be sloped about 1:1 to provide proper bond with the fill. If this is not done, the fill may settle away from the banks and open leakage channels. The entire foundation should next be plowed, scarified, or disked in a direction along the main axis of the dam. This will provide a seal by creating parallel corrugations at right angles to the line of flow. These corrugations act as keyways between the dam and the foundation.

In soils where the imperviousness of the dam foundation is questionable, it is desirable to excavate a narrow core trench lengthwise to the dam and refill it with a damp clay mixture, well compacted. This trench should be dug into an impervious stratum in order to prevent excessive seepage underneath the dam. Figure 36 illustrates such a core trench. Where there is danger of rodents burrowing through the dam or where a pervious surface layer of soil extends to

considerable depths, it may be necessary to use sheet piling instead of a clay core trench. Such core walls are expensive, and except for the larger jobs or where there is no alternative the expense is hardly justifiable. Ordinarily, sites requiring this type of treatment should not be selected.

CONSTRUCTION OF FILL

If a pipe line is to be provided to supply water to a tank below the reservoir it should be installed before work on the earth fill is started. The pipe should be placed in solid ground rather than in fill in order to minimize possible seepage along the pipe. The pipe can be laid in a narrow trench dug either directly across the foundation or along the abutments. The latter method, of course, requires more pipe. Enough grade or fall should be given the pipe so that it will be below frost line on the downstream end of the dam. It can then be fitted with the necessary stopcock and waste cock and brought vertically up to where the stock tank is located. In backfilling the trench, the clay should be well puddled. For carrying stock water a galvanized pipe, preferably not less than 1¼ inches in diameter, should be used. If the outlet is to be used for draining the reservoir or for supplying irrigation water, a larger pipe will usually be required. The larger pipes should be provided with seepage collars spaced at 10- to 20-foot intervals, as shown in figure 16, *A*.

It is generally desirable to have some means available for draining a reservoir. Sometimes it becomes necessary to drain out stagnant water, make repairs to the fill, or puddle the reservoir bed to moderate seepage. Such repair work is difficult if the pond cannot be drained. Siphon pipes over the top of the fill have frequently been used to drain ponds. This arrangement has the advantage of eliminating the seepage hazard often associated with pipes placed through the fill.

Because of the uncertainties of getting suitable soil mixtures and the possible weakening of the fill through stratification, it is advisable to give ample width and height to earth fills. The small added cost incurred in making fills larger than the minimum requirements will be more than offset by the additional security afforded the reservoir. In general, the specifications indicated in figure 30, *B* and *C*, should be considered as minimums. For the fill, an upstream slope of 3:1 and a downstream slope of 2:1 are recommended. The minimum top width (crown width) should be 5 feet for dams up to 10 feet high. Above this height the minimum top width should be approximately $H/5+3$, where H represents the maximum height of the dam in feet. Thus, a dam 15 feet high should have a crown width of at least 6 feet, and one 20 feet high should have a 7-foot crown. The formula is the equivalent of adding 1 foot additional crown width for every 5-foot increase in height of dam. If the dam is to be used as a roadway, a minimum top width of about 12 feet is required. In order to prevent ponding or channeling on the crown, it should be 4 to 5 inches higher along the center and should be sloped toward each face of the dam. This will enable proper drainage of surface water along the top of the dam.

Earth fills more than 15 feet high should preferably have a berm on the downstream slope to provide greater stability, break up the flow of water down the face of the dam, and reduce erosion. The berm should start at the middle of the slope and have a horizontal width of about 4 to 5 feet. The face of the berm should have a slight slope down-

stream. Where good fill material is available and a protective cover of vegetation can readily be established on the fill, the berm may be dispensed with for stock-water reservoirs.

Wherever an adequate depth of impervious soil covers the dam site, the borrow pit for fill material should usually be located upstream from the toe of the dam and in the area to be flooded. At least a 10-foot berm or shoulder should be left between the borrow pit and the toe of the dam. The sides of the pit should be given a slope of at least 2:1. Locating the borrow pit in the reservoir provides additional reservoir depth and capacity and makes unnecessary exposed excavations adjacent to the dam, which are usually difficult to revegetate. If a borrow pit within the confines of the pond will expose pervious substrata it should be located elsewhere.

Fill material for the dam should be applied systematically in uniform layers 5 to 10 inches deep. These should be kept as nearly level as practical and each layer completed over the full width and length of the dam before the next one is started. Moist fill material is preferable in order that the dam may be properly compacted. To obtain a good, firm fill, it is also necessary that each successive layer of dirt be well compacted. This can best be accomplished through systematic tamping as the fill progresses. The travel of teams or tractors over the embankment should be distributed to facilitate compaction. On the larger fills it is usually necessary to use additional compaction measures such as a sheeps-foot roller. Dams have been well compacted by driving cattle, sheep, or hogs repeatedly across the fill. Their sharp hoofs readily compress the soil.

For small stock-pond dams the fill should be carried at least 10 percent higher than the required settled height to allow for settling. A well-compacted fill should not settle as much as that, but this factor of safety is desirable because good compaction or favorable moisture content are frequently not obtainable on small jobs and some unequal settling will therefore probably occur. No fill should be placed during freezing weather, for this may prevent adequate compaction or bonding between layers. No frozen material should be placed in an earth fill.

It is difficult to compact dry fill material, and seepage is likely to occur in a reservoir in which such material is used after it fills with water. When dry fill material is encountered, enough moisture should be added during construction to dampen the surface after each layer is compacted. If it is necessary to add moisture, it should be sprinkled over each finished layer before the next layer is laid. In areas where water is scarce it is usually not feasible to add moisture to the fill even though it may be needed. If the construction work cannot be delayed until natural soil moisture becomes adequate, the undesirable effects of a dry fill may be offset to some extent by adding more width and more height to the fill.

Fill operations are usually carried on with available earth-moving equipment such as scrapers and animal or tractor power (fig. 37). If small equipment is to be used, it is advisable to use several outfits wherever practicable in order not to prolong the construction work unduly and expose it to storm hazards. Rainstorms occurring during the construction period often cause considerable damage and delays. If larger equipment can be rented or made available by community effort or if the work can be contracted, the fill can usually be placed

Tex-15171

FIGURE 37.—Constructing an earth fill with teams and small fresno scrapers. The teams are so distributed as to obtain maximum compaction of the fill.

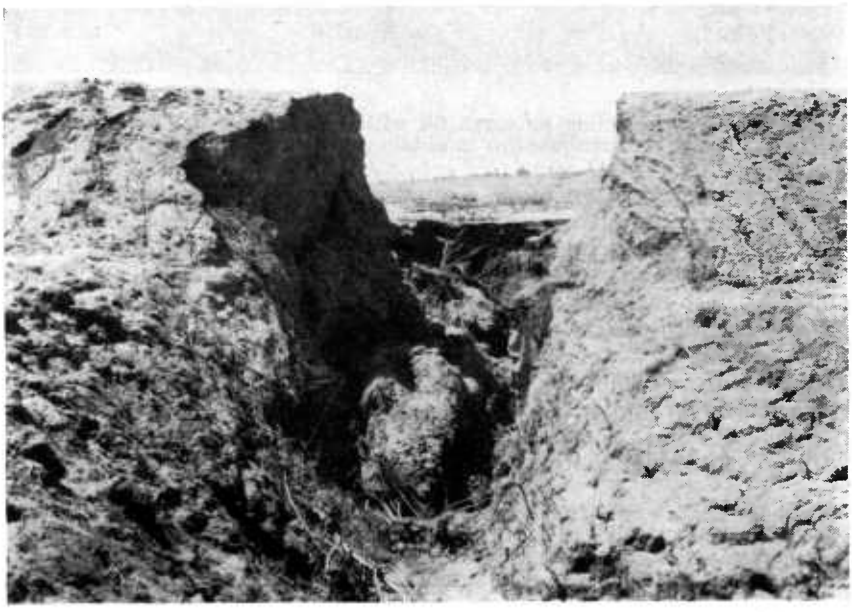
much faster and often more economically. It is difficult to foretell what a job will cost unless similar work has been conducted nearby. It is felt that an average allowance of 15 to 25 cents per cubic yard of fill should be made in cost estimates. This cost presumes a natural spillway, but includes site preparation and fill-protection work. A rough estimate of the job cost can be had by allowing $75 to $150 per acre-foot of water to be impounded. These figures apply to jobs requiring from 1,000 to 3,000 cubic yards of fill. Smaller jobs will have relatively higher unit costs. Table 4 gives the cubic yards of fill per foot of length for earth dams of a wide range of heights and top widths. The side slopes are assumed to be 3 : 1 and 2 : 1.

TABLE 4.—*Cubic yards of fill per linear foot of length in earth dams with a 3:1 slope on the upstream face and a 2:1 slope on the downstream face and top widths of from 5 to 15 feet*

Fill height (feet)	Amount of earth in fills having a top width of—										
	5 feet	6 feet	7 feet	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet
	Cubic yards	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Cubic yards*
5	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.7	4.9	5.1
6	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6.0	6.2	6.4	6.7
7	5.8	6.1	6.4	6.6	6.9	7.1	7.4	7.7	7.9	8.2	8.4
8	7.4	7.7	8.0	8.3	8.6	8.9	9.2	9.5	9.8	10.1	10.4
9	9.2	9.5	9.8	10.2	10.5	10.8	11.2	11.5	11.8	12.2	12.5
10	11.1	11.5	11.9	12.2	12.6	13.0	13.3	13.7	14.1	14.4	14.8
11	13.2	13.7	14.1	14.5	14.9	15.3	15.7	16.1	16.5	16.9	17.3
12	15.6	16.0	16.4	16.9	17.3	17.8	18.2	18.7	19.1	19.6	20.0
13	18.1	18.5	19.0	19.5	20.0	20.5	20.9	21.4	21.9	22.4	22.9
14	20.7	21.3	21.8	22.3	22.8	23.3	23.9	24.4	24.9	25.4	25.9
15	23.6	24.2	24.7	25.3	25.8	26.4	26.9	27.5	28.1	28.6	29.2
16	26.7	27.3	27.9	28.4	29.0	29.6	30.2	30.8	31.4	32.0	32.6
17	29.9	30.5	31.2	31.8	32.4	33.1	33.7	34.3	34.9	35.6	36.2
18	33.3	34.0	34.7	35.3	36.0	36.7	37.3	38.0	38.7	39.3	40.0
19	36.9	37.7	38.4	39.1	39.8	40.5	41.2	41.9	42.6	43.3	44.0
20	40.7	41.5	42.2	43.0	43.7	44.4	45.2	45.9	46.7	47.4	48.2

SPILLWAYS

No matter how well a dam has been constructed, if the capacity of the spillway is inadequate the dam will probably be destroyed during the first severe storm (fig. 38). The force and volume of storm waters are commonly underestimated. Most of the washes and arroyos in which dams are constructed are dry during the greater part of the year. They fill up rapidly during or after a heavy storm, and any impounding structure is exposed to considerable pressure and the hazards of overtopping. Probably the major cause of failure of earth dams is inadequate spillway. Even if a conservative spillway design has been made, it is advisable to allow some extra height to the dam over and above that actually required in order to provide against minor obstructions in the spillway or flaws in fill construction.



Okla—5190

FIGURE 38.—The earth dam was washed out because the spillway failed. Considerable work will be necessary to repair the break.

This added height is commonly referred to as freeboard. It is here assumed to be the depth from the top of the dam to the high-water mark when the spillway is carrying the estimated peak run-off rate resulting from the maximum storm expected within the design period selected for the structure. This freeboard should be not less than 1 foot, and preferably more, depending on the size and cost of the undertaking.

There are several types of spillways that may be used to bypass excess run-off around stock-water dams. They are commonly designated according to the kind of spillway protection provided. Vegetated spillways are used extensively. In these some form of vegetation, usually grass, provides protection against erosion. Mechanical spillways are constructed with concrete, rock, tile, metal,

TABLE 5.—*Recommended discharge capacities* [1] *in cubic feet per second for natural vegetated spillway channels* [2] *of designated dimensions* [3]

Top width, T (feet)	Discharge capacity where the slope is—											
	0.5 percent and depth *d* is—						1 percent and depth *d* is—					
	1.0 foot	1.5 feet	2.0 feet	2.5 feet	3.0 feet	3.5 feet	1.0 foot	1.5 feet	2.0 feet	2.5 feet	3.0 feet	3.5 feet
	C. f. s.	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*
10	2.5	10.5	21.5	35.0	50.5	66.5	3.5	15.0	30.5	50.0	71.5	94.0
20	5.5	21.5	45.0	74.0	109.0	148.0	8.0	30.5	63.5	105.0	154.0	209.5
30	8.5	32.5	67.5	112.5	166.5	227.5	12.0	46.0	96.0	159.5	235.5	322.0
40	11.5	43.0	90.5	151.0	223.0	305.5	16.5	61.0	128.0	213.0	315.5	432.0
50	14.5	54.0	113.0	188.5	279.5	384.0	20.5	76.5	160.0	267.0	395.0	542.5
75	21.5	81.5	169.5	284.0	420.5	577.5	31.0	115.0	240.5	402.0	594.0	816.5
100	29.5	108.5	226.5	378.5	561.5	770.0	41.5	153.5	321.0	536.0	794.0	1,090.5
125	36.5	135.5	284.0	474.0	701.5	965.0	52.0	192.0	402.5	670.5	992.5	1,363.0
150	44.5	163.0	341.0	568.5	842.0	1,158.0	62.5	231.0	483.0	804.5	1,191.0	1,635.5
175	51.5	190.0	398.0	663.0	982.0	1,351.0	73.0	269.5	563.5	938.5	1,390.0	1,908.5
200	59.0	217.5	455.5	758.0	1,123.0	1,544.0	83.5	307.5	644.0	1,073.0	1,588.5	2,184.5
225	66.0	244.5	512.0	853.0	1,263.0	1,737.0	94.0	346.0	724.5	1,207.0	1,787.0	2,458.0
250	74.0	271.5	568.5	947.5	1,403.5	1,930.0	104.5	384.5	805.0	1,341.0	1,985.5	2,731.0
300	89.0	326.5	683.0	1,137.5	1,684.5	2,316.0	125.5	462.0	966.0	1,609.5	2,382.5	3,277.0

Top width, T, (feet)	Discharge capacity where the slope is—										
	2 percent and depth *d* is—						3 percent and depth *d* is—				
	1.0 foot	1.5 feet	2.0 feet	2.5 feet	3.0 feet	3.5 feet	1.0 foot	1.5 feet	2.0 feet	2.5 feet	3.0 feet
	C. f. s.	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*	*C. f. s.*
10	5.5	21.0	43.0	70.5	101.0	133.5	7.0	24.5	48.5	77.5	111.0
20	11.5	43.0	90.0	148.5	218.5	296.0	14.0	50.0	97.5	156.0	222.5
30	17.5	65.0	135.5	225.0	333.0	445.0	21.5	75.5	147.0	233.5	334.0
40	23.5	86.5	181.0	302.0	445.5	593.5	28.5	100.0	196.0	312.0	445.5
50	29.5	108.5	226.5	378.0	556.5	742.0	36.0	125.5	245.5	390.0	556.5
75	44.5	163.0	340.5	568.5	835.0	1,113.5	54.0	189.0	368.0	585.0	835.0
100	59.0	218.0	454.5	758.0	1,113.5	1,484.5	72.0	251.5	491.0	780.5	1,113.5
125	74.0	272.5	568.0	948.0	1,392.0	1,856.0	90.5	314.5	613.5	975.5	1,392.0
150	89.0	327.0	681.5	1,137.5	1,670.5	2,227.0	108.5	378.0	736.5	1,171.0	1,670.5
175	103.5	381.5	795.0	1,326.5	1,949.5	2,598.5	127.0	440.5	859.0	1,366.0	1,949.5
200	118.5	436.0	909.0	1,516.5	2,228.0	2,969.5	145.5	503.5	982.0	1,561.5	2,228.0
225	133.5	490.5	1,022.5	1,706.5	2,506.5	3,341.0	163.5	567.0	1,104.0	1,756.5	2,506.5
250	148.0	545.0	1,136.0	1,895.5	2,785.0	3,712.0	181.5	629.5	1,227.5	1,952.0	2,785.0
300	178.0	654.5	1,363.5	2,275.0	3,342.0	4,454.5	218.0	756.0	1,473.0	2,342.0	3,342.0

Top width, T (feet)	Discharge capacity where the slope is—												
	4 percent and depth *d* is—				5 percent and depth *d* is—				6 percent and depth *d* is—			8 percent and depth *d* is—	
	1.0 foot	1.5 feet	2.0 feet	2.5 feet	1.0 foot	1.5 feet	2.0 feet	2.5 feet	1.0 foot	1.5 feet	2.0 feet	1.0 foot	1.5 feet
	C.f.s.	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*
10	7.0	24.5	48.5	77.5	7.0	24.5	48.5	77.5	7.0	24.5	48.5	7.0	24.5
20	15.0	50.0	97.5	156.0	15.0	50.0	97.5	156.0	15.0	50.0	97.5	15.0	50.0
30	22.5	75.5	147.0	233.5	22.5	75.5	147.0	233.5	22.5	75.5	147.0	22.5	75.5
40	30.5	100.0	196.0	312.0	30.5	100.0	196.0	312.0	30.5	100.0	196.0	30.5	100.0
50	38.5	125.5	245.5	390.0	38.5	125.5	245.5	390.0	38.5	125.5	245.5	38.5	125.5
75	57.5	189.0	368.0	585.0	57.5	189.0	368.0	585.0	57.5	189.0	368.0	57.5	189.0
100	77.0	251.5	491.0	780.5	77.0	251.5	491.0	780.5	77.0	251.5	491.0	77.0	251.5
125	96.0	314.5	613.5	975.5	96.0	314.5	613.5	975.5	96.0	314.5	613.5	96.0	314.5
150	115.5	378.0	736.5	1,171.0	115.5	378.0	736.5	1,171.0	115.5	378.0	736.5	115.5	378.0
175	135.0	440.5	859.0	1,366.0	135.0	440.5	859.0	1,366.0	135.0	440.5	859.0	135.0	440.5
200	154.0	503.5	982.0	1,561.5	154.0	503.5	982.0	1,561.5	154.0	503.5	982.0	154.0	503.5
225	173.5	567.0	1,104.0	1,756.5	173.5	567.0	1,104.0	1,756.5	173.5	567.0	1,104.0	173.5	567.0
250	192.5	629.5	1,227.5	1,952.0	192.5	629.5	1,227.5	1,952.0	192.5	629.5	1,227.5	192.5	629.5
300	231.0	756.0	1,473.0	2,342.0	231.0	756.0	1,473.0	2,342.0	231.0	756.0	1,473.0	231.0	756.0

[1] The discharge capacities have been adjusted where necessary to allow for entrance reduction in flow. It is assumed that the width at the entrance is equal to or greater than the width in the rest of the channel. In either case, the channel width should be used to determine the spillway capacity.
[2] The spillways have been designed for velocities not exceeding the maximum ordinarily recommended in vegetated channels.
[3] It is assumed that the slope is approximately uniform and the channel dimensions substantially the same throughout. A minimum safety factor of 6 inches has been included.

TABLE 6.—*Discharge capacities (cubic feet per second),*[1] *depths,*[2] *and entrance widths*[3] *for constructed vegetated spillway channels with trapezoidal cross section and 4:1 side slopes*

Bottom width b of channel (feet)	Discharge capacity and entrance width where the slope is—																	
	0.5 percent and depth d is—		1 percent and depth d is—		2 percent and depth d is—		3 percent and depth d is—		4 percent and depth d is—		5 percent and depth d is—		6 percent and depth d is—		8 percent and depth d is—		10 percent and depth d is—	
	2 feet 6 inches in channel	3 feet 0 inches at entrance	2 feet 6 inches in channel	3 feet 0 inches at entrance	2 feet 3 inches in channel	3 feet 6 inches at entrance	2 feet 0 inches in channel	3 feet 2 inches at entrance	1 foot 9 inches in channel	2 feet 9 inches at entrance	1 foot 6 inches in channel	2 feet 5 inches at entrance	1 foot 4 inches in channel	2 feet 2 inches at entrance	1 foot 3 inches in channel	2 feet 0 inches at entrance	1 foot 2 inches in channel	1 foot 11 inches at entrance
	Discharge	Width	Discharge	Width	Discharge	Width	Discharge	Width	Discharge	Width	Discharge	Width	Discharge	Width	Discharge	Width	Discharge	Width
	C. f. s.	*Feet*	*C. f. s.*	*Feet*	*C. f. s.*	*Feet*	*C. f. s.*	*Feet*	*C. f. s.*	*Feet*	*C f. s.*	*Feet*	*C. f. s.*	*Feet*	*C. f. s.*	*Feet*	*C. f. s.*	*Feet*
2	55.0	2.0	78.0	2.0	82.0	2.0	68.5	2.0	51.5	2.5	34.5	3.0	23.0	3.5	20.0	4.0	16.0	4.5
4	70.0	4.0	99.0	4.0	104.0	4.0	90.0	4.0	71.0	5.0	50.0	6.0	34.5	6.5	30.5	7.5	25.5	8.5
6	85.0	6.0	120.0	6.0	128.0	6.0	114.0	6.5	91.0	8.0	65.5	9.0	46.5	9.5	42.0	11.5	35.0	12.5
8	100.0	8.0	142.0	8.0	152.5	8.0	137.5	9.0	111.0	10.5	81.0	12.0	58.5	13.0	53.5	15.0	45.0	16.5
10	115.5	10.0	164.0	10.0	178.0	10.0	162.0	11.0	132.0	13.5	97.0	15.0	71.0	16.0	64.5	19.0	54.5	20.5
12	131.5	12.0	186.0	12.0	203.0	12.0	186.0	14.0	152.5	16.5	113.5	18.5	83.0	19.5	75.5	22.5	64.5	25.0
15	155 0	15.0	219.5	15.0	241.5	15.0	222.5	17.5	184.0	21.0	137.5	23.0	101.5	24.5	93.0	28.0	79.5	31.0
20	196.0	20.0	276.5	20.0	306.0	20.0	284.0	24.0	237.0	28.0	178.5	31.0	132.5	33.0	121.5	37.5	104.5	41.5
25	236.0	25.0	333.5	25.0	371.0	25.0	345.5	30.5	289.5	35.5	219.5	39.0	164.0	41.5	150.5	47.0	129.0	51.5
30	277.0	30.0	392.0	30.0	437.0	30.0	408.5	37.0	343.0	43.0	261.0	47.0	195.0	50.0	179.5	57.0	154.0	62.0
35	318.0	35.0	449.5	35.0	503.0	35.5	471.0	43.5	396.5	50.0	302.0	55.0	226.0	58.0	208.5	66.5	179.5	72.5
40	359.0	40.0	507.5	40.0	566.5	40.5	533.0	50.0	450.0	57.5	343.5	63.0	257.0	66.5	237.0	76.0	204.0	83.0
45	400.5	45.0	566.0	45.0	635.0	46.5	595.5	57.0	503.5	65.0	385.0	71.0	288.5	75.0	266.0	85.5	229.0	93.0
50	441.5	50.0	625.0	50.0	701.0	52.0	658.5	63.5	557.5	72.5	426.5	79.0	319.5	83.5	294.5	95.0	254.0	103.5
60	524.5	60.0	741.0	60.0	833.5	63.0	785.0	76.5	664.5	87.5	510.0	95.0	382.0	100.5	353.0	114.0	304.0	124.5
70	606.5	70.0	859.5	70.0	967.0	74.0	910.5	90.0	771.5	102.0	592.5	111.0	445.0	117.5	410.5	133.0	354.0	145.0
80	689.5	80.0	976.5	80.0	1,099.0	85.0	1,037.0	103.0	879.5	117.0	674.5	127.0	507.5	134.5	468.5	152.5	404.5	166.5
90	774.0	90.0	1,093.5	90.0	1,232.0	96.5	1,163.5	116.5	986.5	132.0	758.5	143.5	570.0	151.5	526.0	171.0	454.5	187.0
100	855.0	100.0	1,211.5	100.0	1,359.0	107.0	1,289.0	129.5	1,094.5	147.0	841.0	159.5	633.0	168.5	584.0	190.5	504.0	208.0
125	1,064.0	125.0	1,505.5	125.0	1,697.5	135.0	1,605.0	163.0	1,365.0	184.5	1,048.5	199.5	789.5	210.5	729.0	238.5	629.0	260.0
150	1,273.0	150.0	1,801.0	150.0	2,033.0	163.0	1,921.0	196.0	1,633.0	221.5	1,256.5	240.0	946.0	253.0	874.5	286.5	755.0	312.5

[1] With the capacities given the velocity of the water will not exceed the maximum ordinarily recommended in vegetated channels.

[2] A safety factor of 6 inches has been included in the channel depths and at least a 12-inch safety factor in the entrance depths. The entrance depth should be decreased uniformly through the transition section until it equals the channel depth.

[3] If the entrance width is greater than the width of the channel, the transition section from the entrance to the channel should converge at a slope of 3:1 on each side. All corners should be uniformly rounded.

lumber, or some similar material. Vegetated spillways may be either natural or constructed. Natural vegetated spillways (fig. 30, *B*) are existing drainageways covered with native sod and requiring little, if any, further excavation. Constructed vegetated spillways (fig. 30, *C*) include those that are excavated or shaped to required dimensions and protected by a cover of vegetation established by seeding or sodding. The most common use of mechanical spillways in connection with stock-water reservoirs is in a combination mechanical and vegetated spillway. A concrete, metal, or tile tube or channel, commonly referred to as a trickle spillway, carries a small portion of the run-off, and a vegetated spillway bypasses the remainder.

The maximum rate of run-off to be expected from the contributing drainage area during the estimated life of the reservoir must be determined before it is possible to design or calculate the size of the spillway required. After a survey has been made to ascertain the characteristics of a watershed, the rate of run-off for which the spillway should be designed can be determined from figures 27 and 28. The run-off rates are based on flood flows of 25-year occurrence. If the estimated life of the reservoir is less than 25 years, say, for example, 10 years, the run-off rates from figure 27 should be reduced by about 15 percent, as indicated in the legend for the figure. It is only for large and expensive structures that the spillway need be designed for flood flows exceeding 25-year occurrence. The recommended sizes for vegetated spillways required to carry specified rates of run-off are shown in tables 5 and 6. The sizes include the freeboard indicated in the tables. If a greater safety factor is desired, it can readily be added to the dimensions given.

Natural Vegetated Spillway

A natural spillway should have a broad, relatively flat cross section and preferably should reenter the main channel some distance downstream from the fill. It is also desirable to have the entrance to the spillway a short distance upstream from the fill. The grade of the spillway channel should be mild. So far as possible, natural sod should remain undisturbed, since its destruction will only bring about problems of revegetation. A wide, smooth entrance should be provided for all channels. Fertilizing and seeding may be necessary to improve the spillway cover and should be done where practicable.

Table 5 is suggested for use in determining the approximate capacity of natural vegetated spillways. The parabolic cross section assumed in its compilation will not fit the shapes of all natural spillways, but the capacities recommended in this table will usually be close enough for reasonable accuracy. Use of table 5 will remove much of the uncertainty associated with the customary practice of guessing the capacity of a natural drainageway. Too often the practice has been to utilize an existing drainageway for a natural spillway without investigating its capacity to carry the expected discharge. Note that the depth dimensions in the table include the minimum safety factor of 6 inches recommended for channels. At least another 6 inches should be added to this depth at the spillway entrance to provide a 1-foot minimum freeboard for the dam.

Constructed Vegetated Spillways

The constructed vegetated spillway usually requires some excavation to provide the desired cross section. As in the natural spillway, a broad, flat channel with a low grade is desirable. A common cross section is the trapezoidal with 4:1 side slopes. These flat side slopes facilitate the establishment of nccessary vegetation and subsequent maintenance work. The required size of the channel for various discharges and slopes may be selected from table 6. The dimensions in the table already include the recommended minimum safety factor, both in the channel and at the entrance. Thus for a 1-foot freeboard

Ark-60029

FIGURE 39.—The entrance to this vegetated spillway is too narrow.

at the dam no additional depth above that given in the table for the cntrance need be provided. Attention is directed to the relatively wide entrances required to provide the discharge that the channels are capable of carrying. It is a common mistake in constructing vegetated spillways to provide too small an entrance (fig. 39), and, as a result, the channels will never receive the full discharge they have been designed to carry.

Undue exposure of subsoil and unnecessary destruction of existing vegetation should be guarded against in spillway preparation. In excavating for a vegetated spillway, all topsoil should be removed first and piled conveniently near so that it can later be used in establishing a seedbed in the channel or as a base for sod. Excess dirt may be piled as dikes along the spillway to provide additional channel capacity. Riprapping or other protection at critical points such as the entrance or sharp bends may be advisable. Cover should be established immediately after construction, either by sodding or seeding. Where feasible, sodding is the safer because sod, if properly

anchored, can carry run-off almost immediately after the sod has been placed. Establishing spillway cover by seeding is usually a more hazardous procedure because it takes longer to produce a good cover by seeding than by sodding. A liberal application of fertilizer, careful seedbed preparation, and proper seeding or sodding at favorable seasons and according to proved local procedure are essential for the establishment of satisfactory plant covers. Artificial watering is beneficial at intervals during dry seasons until the grass can establish a dense root system. If run-off is expected immediately, the sod should be anchored with wire or stakes. Seeded channels can be given considerable protection by the use of anchored mulch coverings of straw, cornstalks, brush, or similar material. Wire mesh is excellent for use in anchoring the mulch.

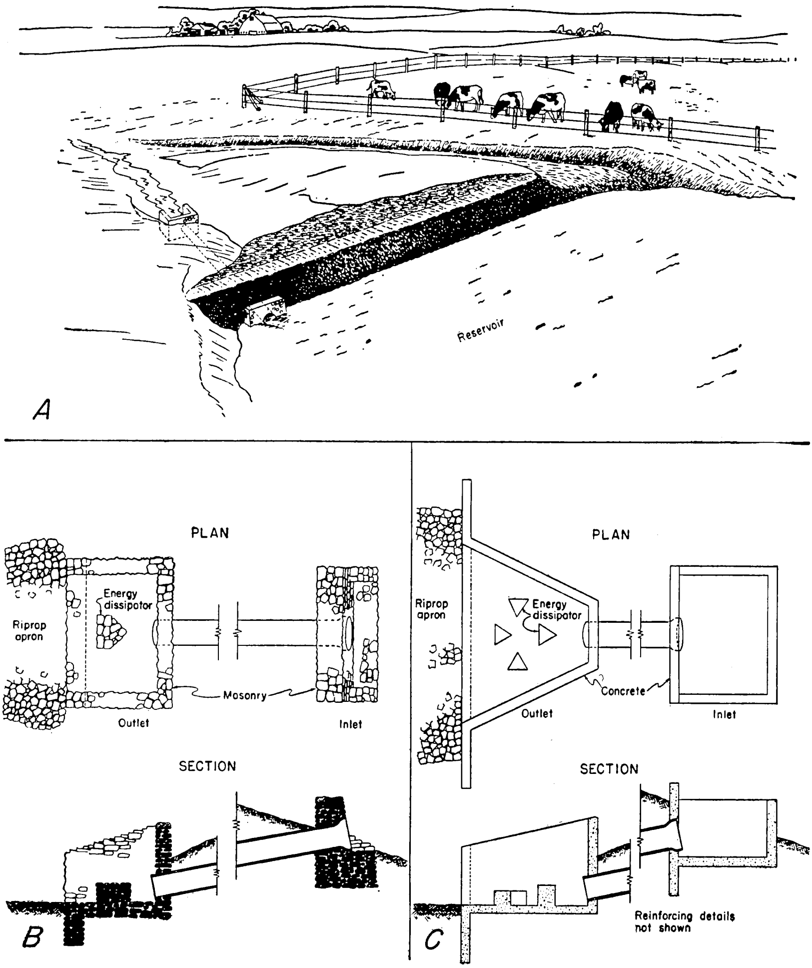
Mechanical Spillways

Trickle spillways (fig. 40) are small secondary spillways that have just enough capacity to carry low flows. This type of spillway is frequently used in connection with vegetated spillways to relieve them of the flow of small discharges that may continue for days after a storm. During the heavy run-off period most of the flow will pass through the main vegetated spillway. Long-continued flow is detrimental to channels covered with vegetation and ultimately may cause their failure. Damage is most likely to occur while the vegetation is becoming established or during seasons when the vegetation is dormant if considerable run-off occurs. The soil in the vicinity of the flow becomes saturated, the vegetal cover loses its binding qualities, and finally a small channel erodes that increases in size with subsequent flows. In areas where good grass covers can be established and maintained, trickle spillways are usually not necessary, especially where the drainage area is small.

Nebr-17

FIGURE 40.—The entrance to a masonry trickle tube. Note the main vegetated spillway on the right. It is at a higher level than the trickle tube.

Trickle spillways are constructed either as small open channels of masonry or concrete or as closed conduits of vitrified tile, galvanized metal pipe, or concrete tubes. Open channels are often brought around the dam on the end opposite the vegetated spillway. This arrangement appears to be more satisfactory than having the trickle



P-2695

FIGURE 41.—*A*, Trickle spillway and auxiliary vegetated spillway. *B*, Rubble-masonry trickle tube inlet and outlet of the kind generally recommended for trickle tubes that have a cross-sectional area of less than 2 square feet. *C*, Trickle tube with concrete inlet and outlet. This type is recommended for larger trickle tubes.

channel within the vegetated spillway because erosion frequently accompanies the latter arrangement. Trickle tubes should preferably be placed in a solid foundation and not in the fill. They are usually installed before the construction of the fill is started. All joints should be carefully sealed and occasional cut-off collars used to prevent seepage along the outside of the tube.

The elevation of the trickle spillway should be at least 1 to 2 feet lower than the crest elevation of the main spillway. This arrangement makes possible the accumulation of a certain amount of pond storage before the main spillway is needed and makes it more likely that the trickle spillway will completely carry most low flows where drainage areas are small and pond areas large. Where trickle spillways are used, the minimum pond depths recommended in figure 21 should be based on the elevation of the trickle spillway rather than that of the main spillway.

Figure 41 illustrates the use and construction of trickle spillways. The specifications are only general and are given as a guide in design. It is recommended that a minimum diameter of 6 inches be used for circular tubes. Table 7 gives suggested minimum sizes for trickle tubes for drainage areas ranging from 5 to 1,200 acres and for storage depths of 1, 2, and 3 feet. The table is based on results obtained from a study of a few representative jobs and should thus be used only where local information on the subject is lacking. Normal watershed characteristics were assumed, and storage capacity was estimated on the basis of computed capacities of average reservoirs. It was further assumed that the main spillway would be designed according to the dimensions in tables 4 or 5. Trickle tubes with diameters much in excess of 15 inches necessitate rather heavy construction and, unless carefully placed, may cause seepage along the tube, which may cause ultimate failure of the dam. Table 7 includes tube diameters only to 24 inches since it is felt that this is about the maximum size that can be justified for average stock-pond construction.

TABLE 7.—*Suggested sizes for trickle tubes used with auxiliary vegetated spillways*

Drainage area (acres)	Diameter of tube for storage depths [1] of—			Drainage area (acres)	Diameter of tube for storage depths [1] of—		
	1 foot	2 feet	3 feet		1 foot	2 feet	3 feet
	Inches	*Inches*	*Inches*		*Inches*	*Inches*	*Inches*
5	6	6	6	200	18	15	12
10	8	6	6	300	21	15	12
20	8	6	6	400	21	18	15
30	10	8	6	500	24	18	15
40	10	8	6	600		21	18
50	12	10	8	800		24	18
100	12	10	10	1,000		24	21
150	15	12	10	1,200			24

[1] By storage depth is meant the difference in elevation between the crest of the main spillway and the bottom of the trickle tube.

Large mechanical spillways usually cannot be justified for use as the main spillway for small stock-water ponds unless no adequate vegetated spillways are available or unless the discharge from the drainage area is so large and continuous that a durable spillway must be provided. Most mechanical spillways will probably be constructed of masonry or concrete. This type of spillway is difficult to construct, and unless the builder has had previous experience with such work, local engineering advice should be obtained.

Fish Screens

Many ponds are stocked with fish, and in order to keep the fish in these ponds during periods of outflow a screen is placed at either the entrance to or within the spillway (fig. 42). This practice restricts the spillway and exposes the structure to overflow hazards. Placing the screen in a vegetated spillway is especially detrimental since it

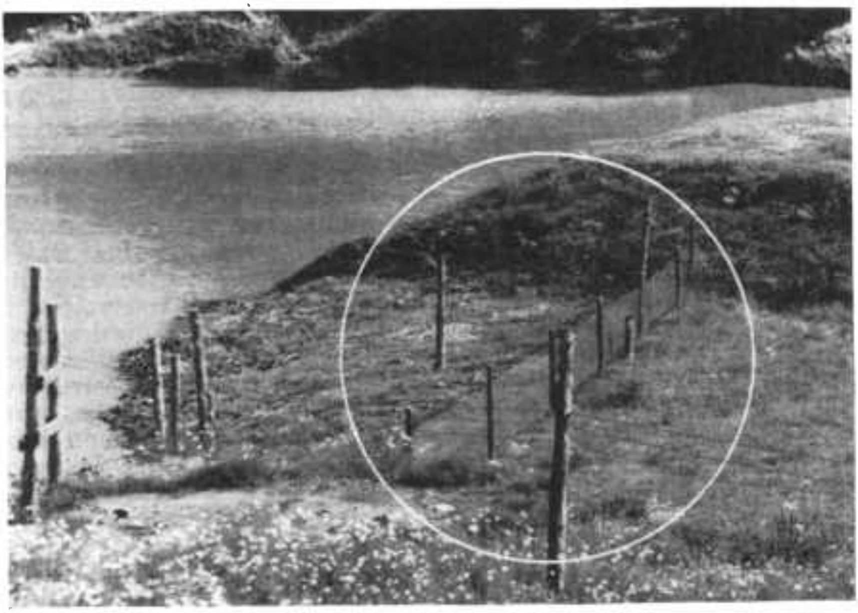


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FIGURE 42.—Many vegetated spillways have been severely damaged because fish screens were placed directly in the spillway entrance, as here.

creates an overfall that soon erodes the spillway. Certain spillways have been completely choked by fish screens clogging with trash. If it is felt that a fish screen is required it should be placed a short distance above the spillway entrance so that it will give minimum interference to the outflow through the spillway. It should be well anchored and frequently inspected and cleaned.

SAMPLE PROBLEM

To familiarize the reader with the design information that has been given for impounding reservoirs, the following sample problem is given. The conditions of this problem are the same as those of the sample problem on page 48, with the exception that the site is favorable for the construction of an impounding reservoir. The farmer estimates that with a dam of 14-foot maximum height he will have a pond with at least 1½ acres of surface area. There is available a natural drainageway near the proposed dam site. This drainageway has a fair cover of grass and a bottom slope of about 1 percent (1 foot drop per 100 feet of length); it will have a top width of about 100 feet for a water depth of 1½ feet.

The formula on page 50 gives the approximate capacity of a reservoir if the surface area and maximum depth of pond are known. The farmer estimates that at spillway level the pond will have a maximum depth of about 10 feet. Then $0.4 \times 10 \times 1.5 = 6$, which is the approximate pond capacity in acre-feet. This is more than enough to supply the water requirements of 2 acre-feet. It has already been determined that the ratio of drainage area to impounded capacity should be at least 47. (See p. 49.) For 6 acre-feet of capacity the number of acres of drainage area required would be 47×6, or 282, and only 200 acres are available. Under those conditions it is probable that the pond will not always fill. If the run-off from additional drainage area cannot be diverted to the reservoir, it is desirable to excavate a relatively deep water hole within the reservoir so that at least some water will be available during dry periods. As was previously noted, figure 21 shows that a reservoir in western North Dakota should have a depth of at least 10 to 12 feet to offset evaporation and ordinary seepage. It is better to get more pond depth than the 10-foot minimum. If subsoil conditions are satisfactory, excavation for the earth fill should therefore be taken from the reservoir to increase its depth.

The drainage area has already been analyzed as having between low and normal run-off-producing characteristics. Using the same classification for flood-producing characteristics would be within reasonable limits of accuracy. Referring to figure 27, we read a peak-flow value of about 150 cubic feet per second (between the low and normal curves). This value is now multiplied by a rainfall factor of 0.7, which is approximately right for western North Dakota (fig. 28). The peak flow in cubic feet per second which the spillway must be able to carry is thus $0.7 \times 150 = 105$.

Referring to table 5, we see that a drainageway such as is here available would carry about 150 cubic feet per second (153.5 is the exact reading for a depth d of 1.5 and top width T of 100 feet). The natural spillway thus has adequate capacity.

PROTECTION AND MAINTENANCE

The construction of a reservoir should not be considered complete until proper protection has been provided. Reservoirs that lack adequate protection may be short-lived, and the amount or cost of subsequent maintenance is usually several times higher than it should be. Reservoirs must be protected from silting, wave action, erosion, burrowing animals, pollution, and the trampling of livestock, as well as from any other source of damage. Good protection requires maintenance. Periodic and systematic inspections should be made, particularly after heavy rains, and the damage resulting from washouts, undercutting, overflow, droughts, rodents, livestock, or any other source, should be repaired immediately. It is a good policy to plan for an average annual maintenance cost of at least 5 to 10 percent of the initial construction and protection work. Under adverse conditions maintenance costs will be much higher if the reservoir is to be preserved and to function as intended.

RIPRAPPING

Protection of the fill against wave action may or may not be necessary. If a body of water comprising several acres of surface has been impounded, in all probability there will be extensive wave action against the fill. This will be true especially if the upstream side of the dam faces toward the prevailing wind or if the wind has unrestricted sweep across the reservoir. For small ponds of only 1 to 2 acres of surface, riprap should ordinarily not be necessary unless wind exposures are unusually severe or the fill material very erodible.

There are several methods of protecting a fill against wave action. One of the best is the use of a layer of rock on a bed of sand or gravel. The rock should be hand-placed to a thickness of 12 to 15 inches or more and should preferably extend from a point 1 foot or more above the spillway elevation to the toe of the dam. In the absence of suitable rock or where a less effective type of protection is satisfactory, a heavy layer of pit-run gravel or even a mat of brush or straw may be used. Brush or straw mats should extend well above and below the normal water level and should be securely anchored. In locations where timber is available, a boom may be constructed by tying logs together and anchoring them in such a manner that they will rise and fall with normal variations in the water surface and float 4 to 5 feet in front of the fill slope (fig. 43). This will effectively break up wave action for a short period. As the logs become waterlogged they will sink unless they are dried out.

On many stock-watering ponds it has been found possible to provide protection from wave action by the use of reeds, rushes, cattails, or other aquatic vegetation adapted to the local area (fig. 44). This vegetation not only provides a cheap form of protection, but it is also conducive to utilization of the pond by wildlife. Protection by

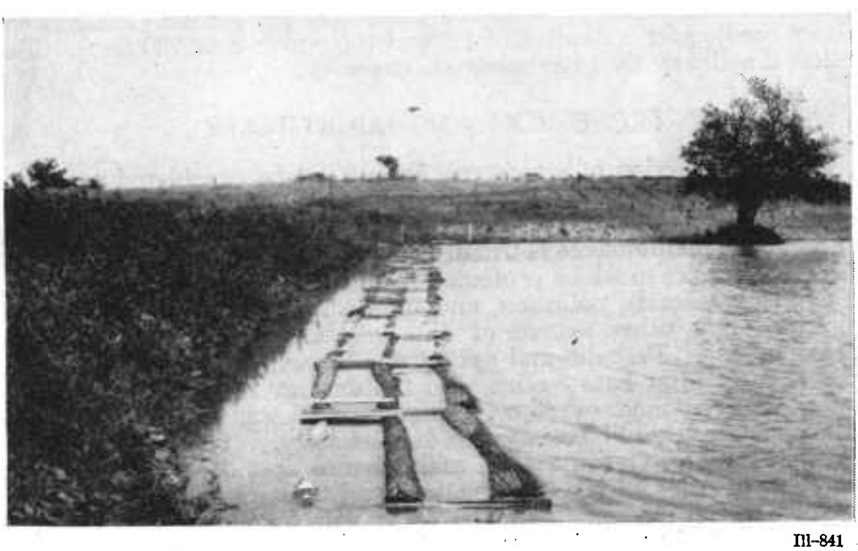

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FIGURE 43.—This log boom protects the dam from wave action. After vegetation on the fill is well established the boom will probably not be needed.

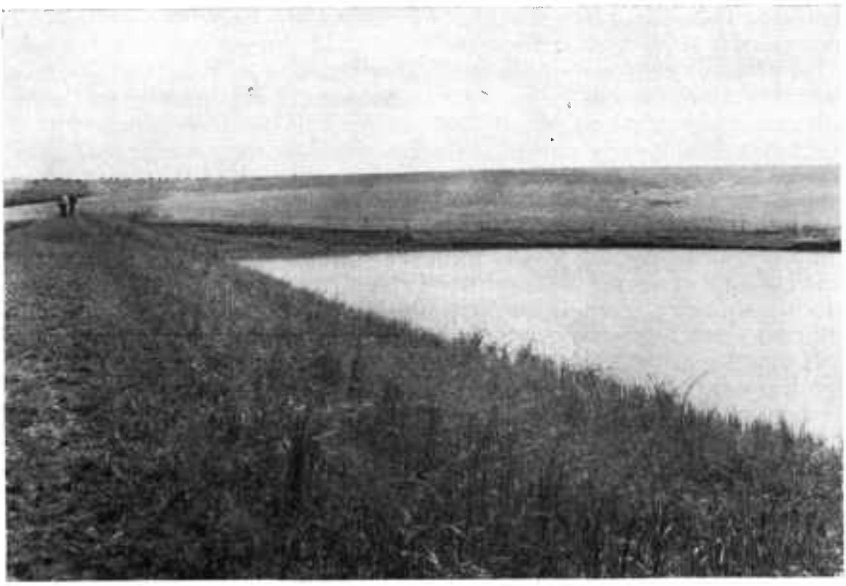

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FIGURE 44.—Stock-water dam with a heavy stand of sloughgrass on the upstream face. This grass can withstand considerable wave action.

the use of aquatic plants may be substituted for the common mechanical forms of riprap protection wherever it is felt that plants will give the necessary protection.

VEGETAL COVER

In most areas the earth fill as well as the spillway must be protected with a cover of vegetation. It is also desirable to provide suitable vegetative protection around the shore line of most reservoirs except where malaria is prevalent. Wherever feasible, a cover of vegetation should be established on the fill immediately after the construction work is completed; otherwise erosion will soon damage the exposed slopes. Sod-forming grass covers are generally preferable on the earth fill. A grass or shrub that thrives in wet soil should probably be used near the water line. The best species of grasses or other vegetation to use and the method of establishment will vary in different parts of the country. In the arid and semiarid sections it is usually difficult and sometimes impossible to establish and maintain a good cover on dry, infertile earth fills. Fortunately, erosion damage is not so severe in these sections, and there is less need for a dense cover.

Establishing satisfactory covers requires considerable patience and ingenuity. Unless the earth fill is capped with fertile topsoil, soil conditions are unfavorable for plant growth. Newly prepared seedbeds, seeds, fertilizers, or even young plants offer little resistance to erosion and are sometimes washed out unless special precautions are taken.

Vegetal covers may be established by seeding or sodding or by a combination of both after a seedbed has been properly prepared and

fertilized. Sodding by sprigging or broadcasting rootstalks and stolons gives good results with Bermuda grass in favorable climates. In other areas direct transplanting of sod in strips or solid covers is usually practiced. If the earth fill is to be seeded, it is generally advisable to sow simple mixtures of adapted grasses and legumes to insure complete stands and early covers. As the quick-growing and less-adapted species thin out the more aggressive ones will spread to replace them and thus perpetuate a continuous cover. Mulching seeded areas with a thin layer of straw, fodder, old hay, or other suitable material not only protects the newly prepared seedbed, seeds, fertilizer, or small plants from run-off and hard rains but conserves moisture and produces a surface condition favorable to the germination and growth of grass seeds.

If maximum wildlife benefits are to be had from a stock-water pond, special planting and management to produce a favorable habitat for fish, waterfowl, and other game or birds is usually necessary. Wildlife is attracted to ponds that provide food, protection, and favorable nesting conditions and does not remain on ponds that lack these requirements. Since wildlife is an asset to the farm, a favorable environment should be provided wherever feasible. Further information on this subject is given in Farmers' Bulletin 1719, Improving the Farm Environment for Wildlife.

FENCING

Even though livestock should usually be excluded from earthen reservoirs and watered by troughs fed from the reservoir a general recommendation that all reservoirs be fenced cannot be made. It is usually more practical to allow livestock to water directly from reservoirs if sufficient ground elevation prevents gravity flow from reservoirs to watering troughs. In some western and midwestern range sections it has also been found that the advantages usually derived from fencing are more than offset by the increased cost and maintenance requirements of fences and the fact that fewer animals can water at one time when reservoirs are fenced and troughs provided. The rancher with numerous widely scattered reservoirs and extensive holdings must have simple installations that require little upkeep and inspection. In favor of leaving reservoirs unfenced, it may be said that the freezing of pipe lines or valves may prevent unattended livestock from getting necessary water. Besides this, a limited amount of reservoir trampling is often beneficial for sealing new reservoirs and packing freshly worked fills.

Fencing critical parts of the reservoir is usually advantageous even if complete fencing may be impractical. After earth dams are settled, continued trampling is usually harmful even in arid regions, and the expense of fencing or the erection of other barriers to keep livestock off the embankment and facilitate the development of protective covers is often warranted. The fencing or exclusion of livestock from vulnerable vegetated spillways, particularly those bypassing run-off from large drainage areas or those with poor vegetal cover, should not be neglected. Failure to develop or maintain necessary covers on spillway areas usually leads to the loss of the entire installation. Complete fencing and exclusion of livestock from a water supply for short intervals is often necessary when it is desirable to

conserve nearby grazing and use the range adjacent to it or near other water supplies.

The complete fencing of impounding reservoirs and the use of separate drinking troughs is ordinarily recommended in the Central and Eastern States. This arrangement (1) provides the protection required to develop and maintain adequate protective vegetation, (2) provides good drinking water and eliminates the danger of livestock damaging or polluting the reservoir, and (3) enables the establishment of an environment beneficial to wildlife. Open ponds, devoid of vegetation, do not attract wildlife, and the type of marshy vegetation required around ponds for satisfactory wildlife cover and protection is not tolerant of much trampling or grazing by livestock. Under general farming conditions, if the number of ponds and the livestock using them is not large for each farm unit and climatic conditions are more conducive to erosion, the advantages of fencing usually outweigh the disadvantages.

SILTING

Effective handling of silt deposition is necessary if surface reservoirs are to be completely satisfactory. Efficient conservation practices must be maintained on the watershed. Special desilting devices and erosion-control work in channels must be maintained and protected if they are to function as intended. Even protected drainage areas will contribute some silt, and occasional cleaning of the reservoir is necessary to maintain pond capacity and depth.

When a storage basin has filled to a considerable depth with mud, it is often more practical to build a new reservoir or raise the old dam than to attempt to remove the silt. If a suitable new site can be found downstream, the old reservoir may be used as a settling basin for catching additional silt and thus prolong the effective life of the new reservoir. Cleaning large quantities of silt from reservoirs with scrapers is a difficult and costly job. The cost of removing a muddy sediment from a reservoir will probably be greater than moving the equivalent amount of dry material for a new fill. The advantage of exerting considerable effort to prevent silt deposition is fully realized after an attempt has been made to clean an old reservoir.

INSPECTION

Stock-water developments should be inspected periodically. It is especially important that new reservoirs be examined after heavy rains to determine whether they are functioning properly or need minor repairs. Discovery of damage and immediate repair usually eliminate the need for more costly repairs later. Damage is usually small at first. If neglected, it may increase until repair becomes impractical and the entire structure must be replaced.

Damaged sod and washed-out fill or spillway should be repaired immediately. Vegetation on spillways and earth fills should be mowed or lightly grazed when necessary to prevent the formation of a rank or undesirable growth. Proper mowing and limited grazing will tend to develop a cover and root system more resistant to run-off. Debris, trash, or any other material that may clog or restrict the capacity of the spillway should be removed. Appurtenances such as fences, pipe lines, float valves, or troughs should also be inspected periodically.

In some localities burrowing animals such as badgers, gophers, and prairie dogs cause severe damage to reservoir fills or spillways. If such damage remains unrepaired it may lead to failure of the dam. A heavy layer of sand or gravel on the fill discourages burrowing to some extent. Poultry netting can also be effectively used, but in time it will rust out. Where pests of this type are the cause of trouble, aggressive trapping and poisoning should be undertaken to prevent further damage and possible loss of the reservoir.

SANITATION

It is desirable to keep stock water clean and reservoir pollution to a minimum. Unnecessary trampling of livestock, particularly hogs, should not be permitted. Gravel, small rocks, or similar material may often be used advantageously for improving approaches to a reservoir. The drainage from barn lot, feeding yards, bedding grounds or any other source of contamination should be diverted from stock-water reservoirs. Dead animals should be removed from the vicinity of the water. Household sewage or other wastes should not be diverted into farm ponds. The scenic and aesthetic advantages of water are universally recognized, and reservoirs should be maintained in an attractive condition wherever feasible. Old machinery, cans, glass, or other rubbish should not be dumped into the reservoir. It is especially important that the water supply be kept clean in ponds from which ice is to be harvested and in those where wildlife is to be harbored.

In areas where surface reservoirs encourage the development of mosquitoes, the reservoirs should be stocked with top-feeding fish. The so-called gambusia minnows are particularly effective in controlling mosquitoes. Where malaria is known to prevail, aquatic growth and shore-line vegetation should not be used, and special precautions must be observed in the construction and maintenance of reservoirs. Most States in malarial sections have health regulations covering these precautions, and they should be followed. It is the responsibility of individuals benefiting from stock ponds to provide necessary anti-mosquito measures and to assure their maintenance. In some areas the development of algae and other forms of plant life in reservoirs may become objectionable. So far as is known, these are harmless, but they may cause disagreeable tastes or odors, encourage bacterial development, and produce an unsightly appearance. Treatment with bluestone (copper sulfate) will check the development of algae. The usual dosage is about 2 or 3 pounds per million gallons of water, and it should be well distributed throughout the reservoir. Overdosage may be harmful to both wildlife and livestock.

U. S. GOVERNMENT PRINTING OFFICE: 1940

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